Potential Groundwater and Surface Water Impacts from the Proposed Dawson Gold Mine, Fremont County, Colorado, USA

Steven H. Emerman, Ph.D., Malach Consulting, LLC, 785 N 200 W, Spanish Fork, Utah 84660, USA, Tel: 1-801-921-1228, E-mail: SHEmerman@gmail.com

Report written for Information Network for Responsible Mining, submitted August 25, 2021

LIGHTNING SUMMARY

The filtered tailings facility for the proposed Dawson underground gold mine in Fremont County, Colorado, would be located 6993 feet from Cañon City (population 16,693). The proposal does not recognize that the structural zone that would confine the lightly-compacted filtered tailings constitutes a dam that should conform to dam safety standards and includes no consideration of the consequences of dam failure. The predicted water consumption by the mine (9.8 gallons per minute) is not justified and is an order of magnitude lower than the average for the gold mining industry.

EXECUTIVE SUMMARY

The Canadian company Zephry Minerals Ltd has submitted an application for the Dawson underground gold mine in Fremont County, Colorado. The mine would operate for five years and would process 330.8 US tons of ore per day for conversion into gold concentrate. The remaining 546,531 US tons of tailings would be filtered to a water content of 15% and permanently stored on-site. The filtered tailings storage facility would be located 6993 feet upslope from Cañon City (population 16,693) and 1180 feet upslope from a Bureau of Land Management (BLM) Area of Critical Environmental Concern. The mine would consume 9.8 gallons of water per minute, including 6.2 gallons per minute from a fresh water supply well, 1.1 gallons per minute from dewatering the underground mine, and 2.5 gallons per minute from water stored within the ore. There are numerous contradictions both internally and among the application, its appendices, and the earlier Technical Report provided to investors. As a single example, although the height of the filtered tailings facility would be 121 feet after five years, the seepage analysis assumed a maximum tailings thickness of only 28 feet. The seepage analysis was used to argue that seepage would be negligible, so that no liner would be needed under the filtered tailings.

The predicted water consumption is not justified and includes evaporation of only 2.2 gallons per minute from the entire mine site. By contrast, the predicted water consumption is 18.4% and 6.6% of the average for the gold mining industry, based on ore production and gold production, respectively, even after adjusting industry averages for the reduction in water consumption resulting from filtered tailings technology. According to the application, the mine dewatering would result in drawdowns as high as 285 feet at the mine location. Drawdowns greater than 5 feet in the hard rock and in the sedimentary Dakota Formation would extend 1.1 miles and 0.9 miles, respectively, from the mine location. The application calculated the drawdowns that would occur over 10 years and did not calculate the long-terms impacts of dewatering or the time required to restore the equilibrium of the groundwater system. The application also did not consider the additional drawdown that would result from pumping the

fresh water supply well. The Technical Report mentions the possibility of water treatment before water is discharged into the environment from the mine site, but none of the documents includes any plan for a water treatment plant. There is no mention of the possibility of water treatment for the water that is recycled through the mining operation and no analysis of the increase in the dissolved solids content of the process water that could occur due to recycling without chemical treatment. In fact, saturation of the process water could result in precipitation of salts on all contact surfaces and in the tailings filter presses, which would render the filter presses non-functional. In addition, there is no discussion as to how the process water could still function to extract the gold concentrate with a high dissolved solids content.

The plan for the filtered tailings storage facility includes a structural zone for confinement of the tailings that are too wet for proper compaction. The application never uses the word "dam" and does not recognize that the structural zone constitutes a dam that should conform to dam safety standards. The structural zone/dam would be constructed using the upstream method in which the dam is built on top of the tailings that it is confining. In the event of the liquefaction of the tailings, the dam will collapse into the underlying tailings. For that reason, the method of upstream construction is illegal in Brazil, Chile, Ecuador and Peru. The application includes no consideration of the circumstances under which the tailings will undergo liquefaction and no consideration of the consequences of failure of the filtered tailings facility. According to a statistical model of past tailings dam failures, following failure of the tailings dam at the Dawson mine, under the most-likely scenario (loss of 35% of the stored tailings after 5 years of operation), the tailings will travel 11,905 feet during the initial runout. Under the worst-case scenario (loss of 100% of the stored tailings after 5 years of operation), the tailings will travel 37,098 feet (over 7 miles) to Grape Creek and then to the Arkansas River and through the center of Cañon City during the initial runout. Subsequent normal fluvial processes will transport the tailings indefinitely down the Arkansas River. Based on Colorado, as well as most national and international dam safety standards, and the potential for loss of human life and habitat destruction following dam failure, the filtered tailings facility should be designed to withstand at least 90% of the Probable Maximum Precipitation (PMP).

The static stability analysis of the filtered tailings facility resulted in a factor of safety FS = 1.59, where FS = 1.00 indicates a tailings facility on the cusp of failure. However, with the exception of the tailings densities, all geotechnical input parameters for the stability analysis were assumed without justification. The tailings densities were based on measurements on tailings samples from a different ore deposit (Windy Gulch) and an assumed ability to compact the tailings to 95% of the maximum density within the structural zone. There was no mention of the assumed height of the water table or any discussion of the water table height that would result in dam instability or the circumstances under which such a water table height would occur. The filtered tailings facility would be constructed with diversion channels (contact water ditches) to prevent rewetting of the filtered tailings by surface runoff. The diversion channels would be designed to accommodate a 24-hour storm with a return period of 10 years during mine operation. On that basis, the probability of rewetting the tailings by runoff would be 10% in any given year of mine operation and 41% over the five years of mine operation. Following mine closure, the diversion channels would be reconstructed to accommodate a 24-hour storm with a return period of 100 years, so that the probability of rewetting the tailings by runoff would be 1% in any given year of the indefinite period of mine closure. There is no analysis of the consequences of rewetting either in terms of dam stability or increasing the susceptibility of the tailings to liquefaction.

TABLE OF CONTENTS

OVERVIEW

Zephyr Gold USA Ltd, a wholly-owned subsidiary of the Canadian mining company Zephyr Minerals Ltd, has submitted an application to open the Dawson underground gold mine in Fremont County, Colorado (Environmental Alternatives, 2021a-b; see Fig. 1). The mine would operate for five years and would process 330.8 US tons of ore per day into a gold concentrate that would be shipped elsewhere for further refining (Environmental Alternatives, 2021a). (Throughout this report, distinction will be made between the US ton (2000 pounds) and the metric ton (1000 kilograms)). The tailings are the crushed rock particles that remain after the commodity of value has been removed. The 546,531 US tons of tailings remaining after five years of operation would be filtered to a water content of 15% and permanently stored on-site. The filtered tailings storage facility would be located 6993 feet upslope from Cañon City (population 16,693) and 1180 feet upslope from a Bureau of Land Management (BLM) Area of Critical Environmental Concern (see Figs. 2-3).

The objective of this report is to answer the following question: Does the application for the Dawson mine (Environmental Alternatives, 2021a-b) provide sufficient protection to groundwater and surface water resources? Before discussing the methodology for addressing the above question, I will first review some important topics related to water use and water consumption by mines and then to mine tailings and tailings dams. The review will be followed by further information about the water balance and the tailings management plan for the proposed Dawson gold mine. It should be noted that none of the documents related to the Dawson gold mine (Golder Associates, 2017; Environmental Alternatives, 2021a-b) ever use the word "dam." The significance of this omission will be a key aspect of this report.

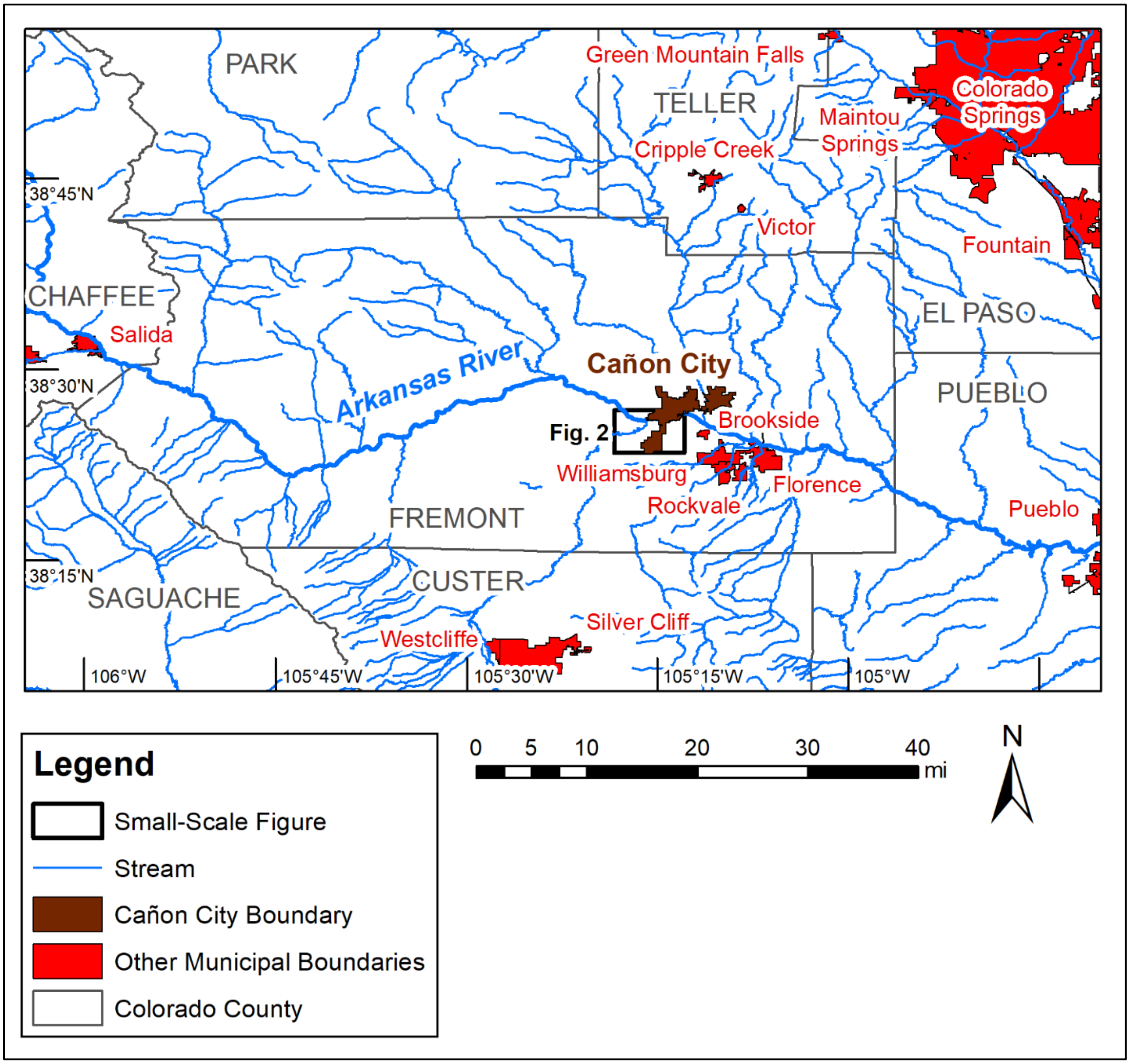

Figure 1. The Canadian mining company Zephyr Minerals Ltd has submitted a proposal for the Dawson gold mine immediately west of Cañon City (population 16,693) in Fremont County, Colorado. County and municipal boundaries from ColoradoView (2021). Streams from National Hydrography Dataset (USGS, 2021).

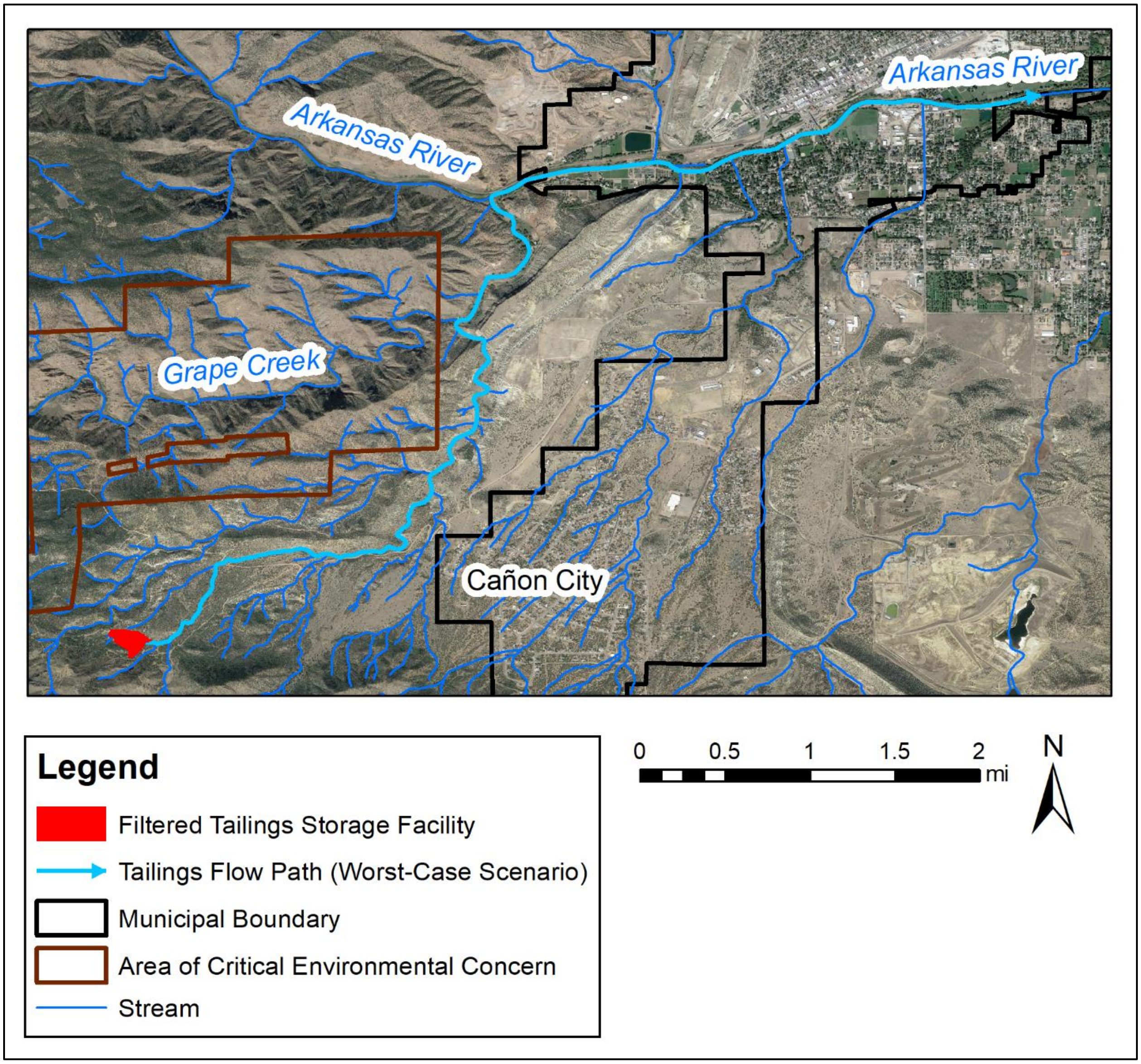

Figure 2. The filtered tailings storage facility for the proposed Dawson gold mine would be located 1180 feet from a BLM Area of Critical Environmental Concern and 6993 feet from the municipal boundary of Cañon City. According to a statistical model of past tailings dam failures, following failure of the tailings dam at the Dawson mine, under the worst-case scenario (loss of 100% of the stored tailings after 5 years of operation), the tailings will travel 37,098 feet (over 7 miles) to Grape Creek and then to the Arkansas River and through the center of Cañon City during the initial runout (see Table 1). Subsequent to the initial runout, normal fluvial processes will transport the tailings farther downstream the Arkansas River (see Fig. 1 for larger-scale view). Streams from National Hydrography Dataset (USGS, 2021), municipal boundary from ColoradoView (2021), and Areas of Critical Environmental Concern from BLM (2021). Filtered tailings storage facility traced from Environmental Alternatives (2021b). Background is Google Earth image from October 5, 2019.

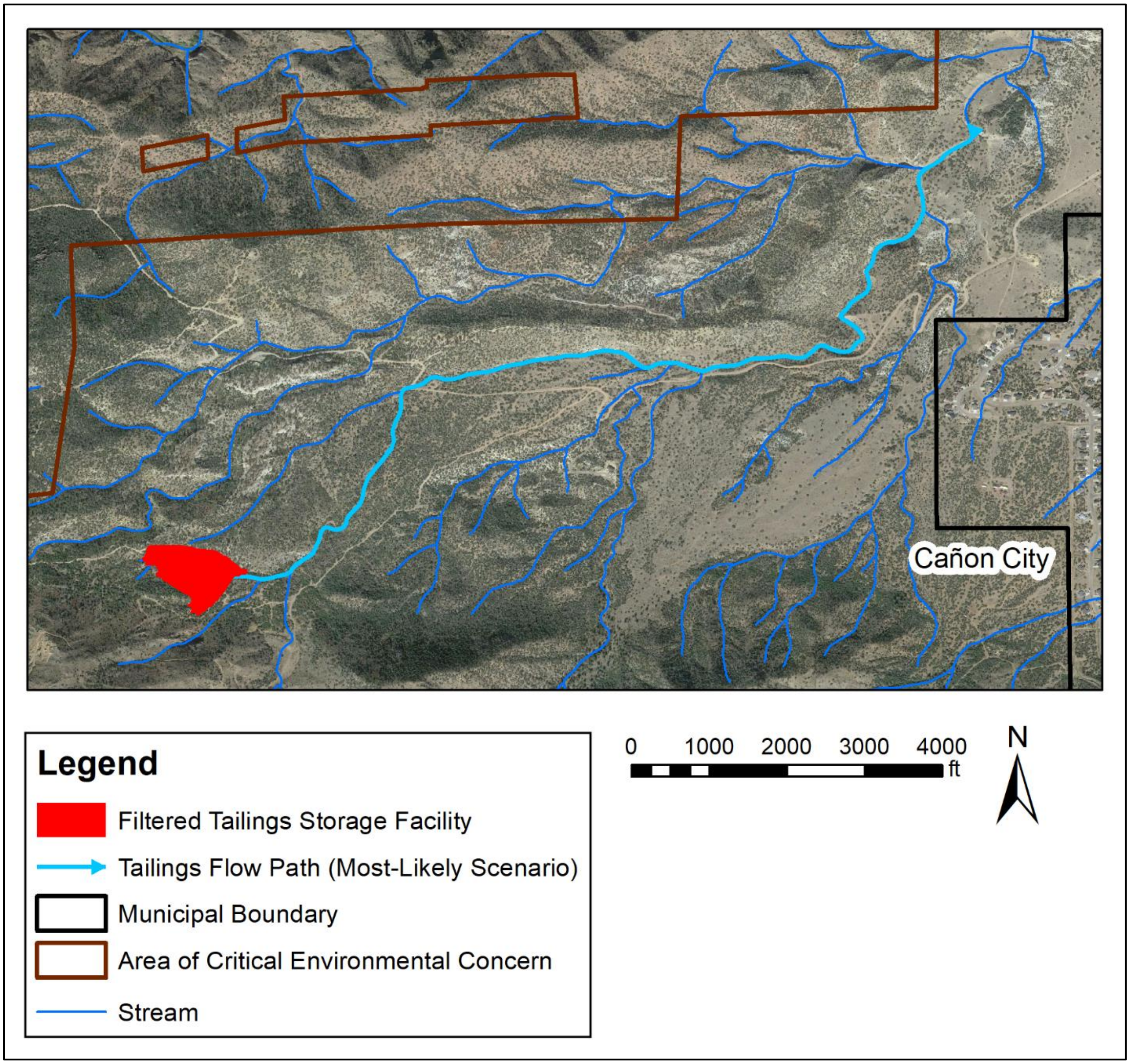

Figure 3. The filtered tailings storage facility for the proposed Dawson gold mine would be located 1180 feet from a BLM Area of Critical Environmental Concern and 6993 feet from the municipal boundary of Cañon City. According to a statistical model of past tailings dam failures, following failure of the tailings dam at the Dawson mine, under the most-likely scenario (loss of 35% of the stored tailings after 5 years of operation), the tailings will travel 11,905 feet (over 2 1/4 miles) (see Table 1) during the initial runout. Subsequent to the initial runout, normal fluvial processes will transport the tailings to Grape Creek and then to the Arkansas River (see Fig. 2). Streams from National Hydrography Dataset (USGS, 2021), municipal boundary from ColoradoView (2021), and Areas of Critical Environmental Concern from BLM (2021). Filtered tailings storage facility traced from Environmental Alternatives (2021b). Background is Google Earth image from October 5, 2019.

REVIEW OF WATER USE AND WATER CONSUMPTION

With regard to evaluating the potential impacts of a mining project on groundwater and surface water resources, the most important concept is the distinction between water use and water consumption. This distinction was expressed by Environmental Alternatives (2021a) in writing, "The mine is proposed to operate 365 days per year and annual demands are estimated at approximately 200 acre feet during operation. As noted, a significant portion of this water demand will be provided by the reuse of water supplies within the mining process so once the reclaim water, filtered water and potable water tanks are full, they will only need to be topped off periodically." In this sense, the rate at which water circulates or is recycled through the mining operation is called "water use," while "water consumption" refers to the rate at which mine water must be replaced by withdrawals from groundwater or surface water resources. Water consumption is also called the "blue water footprint" and results from water lost by evaporation, water that is incorporated into the product (such as a gold concentrate) and shipped off-site, water that is permanently entrained within mine tailings, and water that is not returned to the same catchment area from which it was withdrawn (Northey and Haque, 2013). The extent of mine water recycling ranges from 0-96% (Mudd et al., 2017), so that water consumption is always less than or equal to water use, and can be much less than water use.

Although reporting of water consumption by mining companies is not entirely consistent, it typically includes water added to the mining operation from supply wells, surface water bodies, and dewatering of open-pit and underground mines. Although precipitation and surface runoff onto a mine site are certainly water inputs, they are not typically included in calculations of water consumption rates. In fact, the "Water Accounting Framework for the Minerals Industry" published by the Minerals Council of Australia and the Sustainable Minerals Institute explicitly excludes precipitation from calculations of mine water consumption and recycling rates (Northey and Haque, 2013). The apparent reason is that withdrawal from groundwater and surface water resources requires permits because it can affect the availability of water to surrounding water consumers, although there are jurisdictions that also regulate and require permits for rainfall harvesting. The input into the mining operation of water that was stored in fractures or pores within ore bodies could be regarded as a variation on mine dewatering. The use of water stored in ore bodies typically does not require an additional permit and is sometimes, but not always, counted as part of water consumption. In any event, the input of water stored within the ore bodies is generally a minor part of the water consumption of a mining operation. The proposed Dawson gold mine is an exception, which will be discussed in the section Summary of Dawson Mine.

REVIEW OF TAILINGS AND TAILINGS DAMS

Liquefaction

A mass of mine tailings consists of solid rock particles in which the pores between the particles are filled with a combination of air and water. From an engineering perspective, a mass of mine tailings is a type of soil. Of course, from an agricultural perspective, a soil should include organic matter and organisms and be able to support the growth of higher plants. However, these biological properties are not relevant for engineering purposes. An excellent reference for more complete information on the engineering properties of soils is Holtz et al. (2011). The phrases "soil" and "mass of tailings" will be used interchangeably in this subsection, which largely follows the presentation in Holtz et al. (2011).

A normal stress means any stress that is acting perpendicular to a surface (see Fig. 4). A normal stress acting on a soil can be partially counterbalanced by the water pressure within the pores. The effective stress is defined as the normal stress minus the pore water pressure. The effective stress is a measure of the extent to which the solid particles are interacting with or “touching” each other (see Fig. 4). The normal stress without subtracting the pore water pressure is also called the total stress.

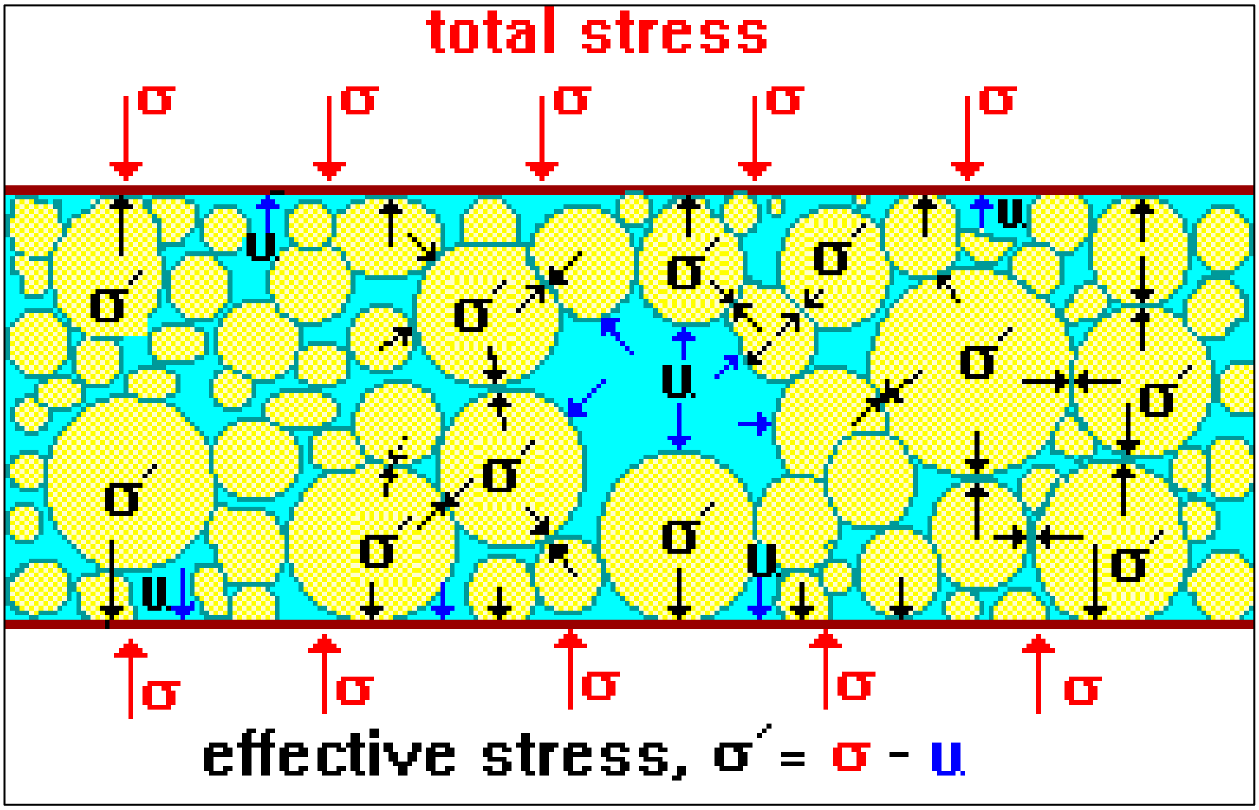

Figure 4. The effective stress in soil is equal to the total stress minus the pore water pressure. The effective stress is a measure of the extent to which the solid particles are interacting with or “touching” each other. Terzaghi’s Principle states that the response of a soil mass to a change in stress is due exclusively to the change in effective stress. Figure from GeotechniCAL (2021).

Terzaghi’s Principle states that the response of a soil mass to a change in stress is due exclusively to the change in effective stress (Holtz et al., 2011). For example, suppose that sediments are deposited on a river floodplain or tailings are hydraulically discharged into a tailings reservoir without compaction. The weight of the solid particles creates a normal stress, so that the particles will consolidate under their own weight. The amount and rate of consolidation is determined by the effective stress, that is, the extent to which the particles are interacting with each another. Sufficient water pressure can offset the normal stress, so that little consolidation could occur and at a slow rate.

The phenomenon of liquefaction, in which a soil loses its strength and behaves like a liquid, can be explained through an application of Terzaghi’s Principle (see Fig. 5). In the diagram on the left-hand side of Fig. 5, although the solid particles are loosely packed and the pores are saturated with water, the particles touch each other. Because there is contact between the particles, the load (the weight of particles or other materials above the particles shown on the left-hand side of Fig. 5), is carried by the solid particles. The load is also partially borne by the water due to the water pressure. The term permeability refers to the ability of water to flow through the pores. A mix of coarse and fine particles will have low permeability because the finer particles will fill in the pores between the coarser particles and, thus, restrict the pore space for water flow.

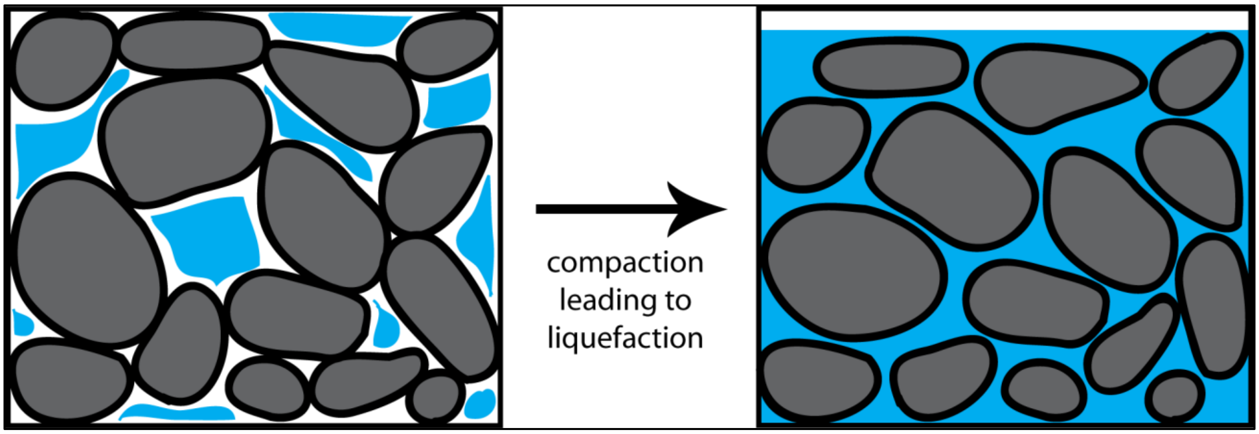

Figure 5. In the diagram on the left, although the solid particles are loosely packed and the pores are saturated with water, the particles touch each other, so that the load is supported by the particles (and partially by the water). Loose-packing means that the soil is in a contractile state, so that the solid particles will tend to compact to a more densely-packed state following an increase in load or a disturbance (such as an earthquake). If the water cannot escape (due to low permeability or the speed of the disturbance), the solids cannot compact so that the additional stress is converted into an increase in pore water pressure (see the diagram on the right). The increased water pressure can decrease the effective stress almost to zero or to the point where the particles no longer “touch” each other (see Fig. 4). At this point, the soil mass has undergone liquefaction in which the water supports the entire load and the mass of particles and water behaves like a liquid. This phenomenon of liquefaction is promoted by saturated pores and loosely-packed particles. If the pores are unsaturated prior to the disturbance, some compaction can occur (decreasing the size of the pores), so that the pores become saturated. Any further contractile behavior will then convert the additional stress into increased pore water pressure. On that basis, liquefaction is possible even if the pores are only 80% saturated. Figure from DoITPoMS (2021).

Loose-packing means that the soil is in a contractile state, so that the solid particles will tend to compact to a more densely-packed state following an increase in load or a disturbance (such as an earthquake). If the water cannot escape (due to low permeability or the speed of the disturbance), the solids cannot compact so that the additional stress is converted into an increase in pore water pressure (see right-hand side of Fig. 5). The increased water pressure can decrease the effective stress almost to zero or to the point where the particles no longer “touch” each other (see Fig. 4). At this point, the soil mass has undergone liquefaction in which the water supports the entire load and the mass of particles and water behaves like a liquid.

This phenomenon of liquefaction is promoted by saturated pores and loosely-packed particles. Even if the pores between loosely-packed particles are unsaturated prior to the disturbance, some compaction can occur (decreasing the size of the pores), so that the pores become saturated. Any further contractile behavior will then convert the additional stress into increased pore water pressure. On that basis, liquefaction is possible even if the pores are only 80% saturated. There is a considerable literature on methods for evaluating the susceptibility of soil or tailings to liquefaction (Fell et al., 2015). For example, a mix of fine and coarse particles could make the tailings more susceptible to liquefaction by reducing their permeability (the fine particles will fill in the pores between the coarse particles).

Filtered Tailings Technology

Filtered tailings technology seeks to address two important problems in mining by dewatering the tailings before they are shipped to the tailings storage facility:

1) The water consumption can be reduced by recycling the water from the tailings back into the mining operation.
2) The likelihood of liquefaction of the tailings can be reduced by desaturating the tailings and then by compacting the tailings as they are stored in a filtered tailings storage facility.

In conventional tailings management, the tailings are shipped to the tailings storage facility with no dewatering, so that the water content of the tailings is in the range 150-400%, although it can be as low as 67%, where water content is the ratio of the mass of water to the mass of solid tailings. High-density thickened or paste tailings technology dewaters the tailings to water contents in the range 33-67% prior to export to the tailings storage facility, while filtered tailings technology dewaters the tailings to water contents less than 25%. Conventional tailings behave like a wet slurry, while high-density thickened or paste tailings behave like a paste (as the name implies), and filtered tailings behave like a moist soil. The boundaries between the different tailings technologies depend upon the physical and chemical properties of the tailings, and is defined by physical behavior, not water content (Klohn Crippen Berger, 2017).

The application for the Dawson mine (Environmental Alternatives, 2021a) repeatedly refers to the tailings as "dry," which is non-standard terminology. For example, according to Environmental Alternatives (2021a), "A dry-stack tailings system is proposed for DGM [Dawson Gold Mine] … The seepage, as well as runoff from the dry stack, will be directed to a geomembrane lined contact water pond downstream of the FTSF [Filtered Tailings Storage Facility] … The combination of dry stack tailings, stormwater diversion channels, the geomembrane lined contact water pond, stack monitoring and the semi-arid climate of the area will contribute to achieving a FTSF that will be inert and not susceptible to oxidation over time." The tailings are not literally dry and, if they were, it would be impossible to properly compact them for safe storage. In fact, based on measurements on tailings from a different ore deposit (Windy Gulch), Environmental Alternatives (2021a) states that the optimum water content for maximum compaction of tailings from the Dawson ore deposit would be 15.9%. On their website, the consulting company Knight-Piésold includes a publication by employees of Knight-Piésold that states, "Regarding terminology, the rather misleading term dry stack is generally not a good engineering term since the target moisture content coming from the filter plant is typically desired to be somewhere around the optimum moisture content based on the Proctor compaction procedure … Geotechnical engineers associate the optimum moisture content with moisture levels just below full saturation after compaction, thus terming such a facility as a dry stack is a misnomer. The present authors would encourage practitioners to abandon the use of the term dry stacking in favor of the more straightforward term, 'filtered tailings.' It is not desirable to unintentionally mislead the public at large with an industry term that is noticeably misused" (Ulrich and Coffin, 2017). In this report, the tailings will be referred to as "filtered" rather than "dry," except to quote from documents provided by Zephyr Minerals Ltd or their consultants.

A simple comparison of the preceding water contents for the different categories of tailings overstates the reduction in water consumption that can be achieved by the transition from conventional to filtered tailings technology. The reason is that, within the tailings storage facility, the solid tailings will settle out of suspension so that the supernatant water can be recycled back into the mining operation. For example, a typical mill will export to the tailings storage facility

70 US tons of water for every 30 US tons of solid tailings (see Fig. 6). In a typical conventional tailings storage facility, of those 70 US tons of water, 7 US tons of water will remain entrained within the tailings, while 63 US tons of water will be released at the tailings facility and recycled back into the mining operation (see Fig. 6). The progression from conventional to thickened to high-density thickened to paste tailings technology increases the proportion of water that is recycled through dewatering of the tailings prior to shipment to the tailings storage facility ("reclaimed during processing") and decreases the proportion of water that is recycled out of the tailings storage facility ("released at tailings facility") (see Fig. 6). However, the end result from a water consumption standpoint does not change, namely that typically, for every 30 US tons of solid tailings, 7 US tons of water remain permanently entrained within the tailings (see Fig. 6). The step change occurs in the transition to filtered tailings technology, in which, typically, no water can be recycled from the filtered tailings storage facility, while 5 US tons of water remain entrained within the tailings for every 30 US tons of solid tailings (see Fig. 6). In summary, the typical reduction in water consumption through the use of filtered tailings technology is 2 US tons of water for every 30 US tons of solid tailings, in comparison to any other tailings management technology (Klohn Crippen Berger, 2017).

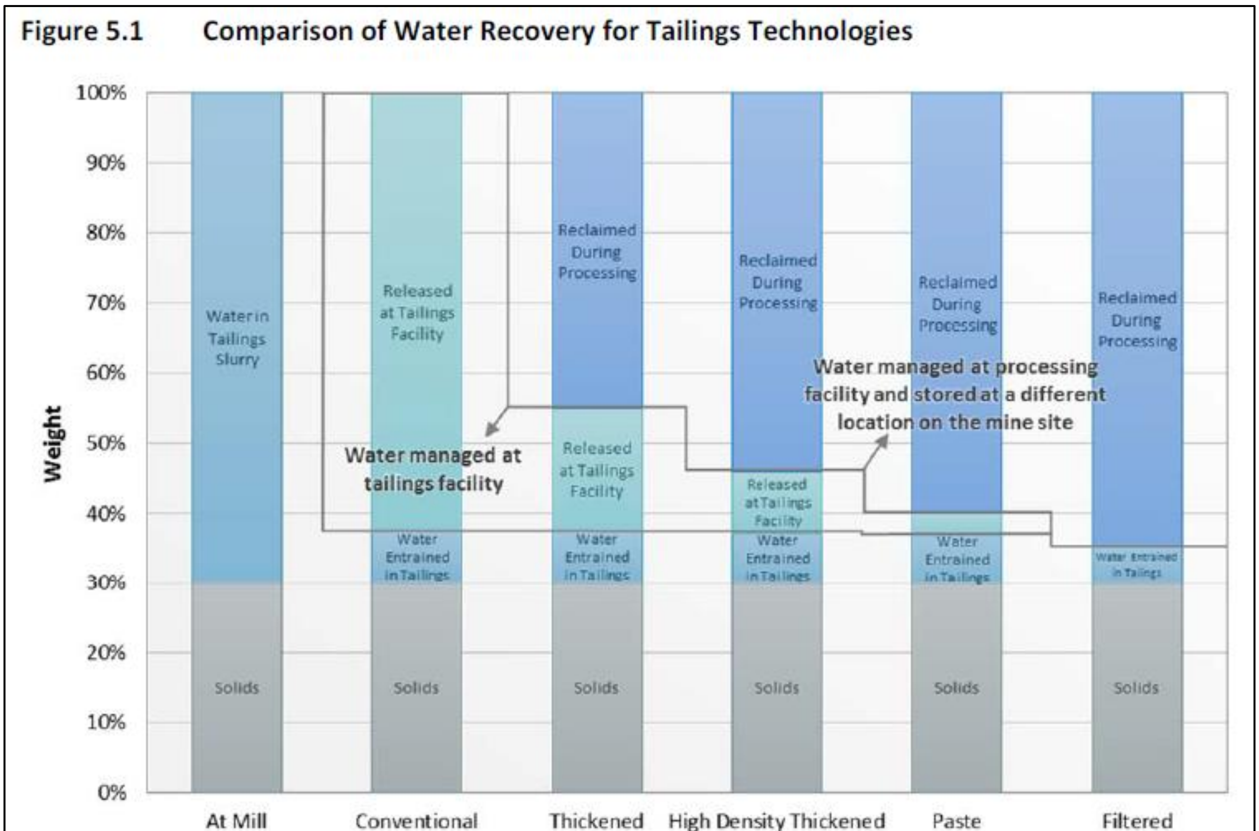

Figure 6. In conventional, thickened, high-density thickened, and paste tailings technology, for every 30 US tons of solid tailings, the water entrained in the tailings has a mass of 7 US tons. This entrained water is not released as the tailings settle out of suspension and is generally non-recoverable and, thus, a component of water consumption. In filtered tailings technology, for every 30 US tons of solid tailings, the non-recoverable water entrained in the tailings has a mass of 5 US tons. Therefore, the reduction in water consumption resulting from the use of filtered tailings technology is 2 US tons of water for every 30 US tons of tailings. Some additional reduction in waster consumption could occur through reduction of evaporation at the tailings facility. Figure from Klohn Crippen Berger (2017).

An additional source of reduction in water consumption through filtered tailings technology is the reduction in evaporation through the elimination of a free water surface on top of the tailings. The evaporation from the tailings pond is highly variable and depends upon solar radiation, water temperature, and atmospheric factors, such as air temperature, relative humidity and wind speed, as well as the technologies that can be used to reduce evaporation. According to Spiller and Dunne (2017), "The amount of evaporation of water from the TSF [Tailings Storage Facility] may range from about 5% to more than 60% of the total water lost at a TSF." On that basis, at the lower end of evaporation (5% of total water loss), for every 7 US tons of water entrained within the tailings, another 0.4 US tons of water will be lost to evaporation. At the higher end of evaporation (60% of total water loss), for every 7 US tons of water entrained within the tailings, another 10.5 US tons of water will be lost to evaporation. Thus, the reduction in water consumption through a conversion to filtered tailings technology could be as high as 12.5 US tons of water for every 30 US tons of tailings if the conversion occurred from a existing or planned facility with extremely high evaporation and no other technologies for reducing evaporation. On the other hand, the tailings pond can also be a source of water through the capture of precipitation and surface runoff (Klohn Crippen Berger, 2017). Most case studies regarding conversions to filtered tailings technology have not explicitly taken into account any reduction in water consumption through reduction in evaporation from the tailings pond (e.g., Gagnon and Lind, 2017; Moreno et al, 2018).

Filtered tailings technology reduces the likelihood of liquefaction of the tailings pile through desaturating the pore spaces between the tailings, reducing the overall quantity of water in the tailings storage facility, and compacting the tailings within the tailings storage facility. This compaction reduces the likelihood of liquefaction by putting the tailings into a dilative (as opposed to contractile) state in which they will expand rather than consolidate when they are sheared or disturbed. Most typically, filtered tailings storage facilities are constructed with an outer shell of compacted tailings (sometimes called the "structural zone") surrounding an inner core of uncompacted or lightly compacted tailings (see Fig. 7). Although some recent mining project plans have claimed that filtered tailings do not require a dam, the structural zone fulfills the exact same function as a dam, that is, it is an engineered structure that prevents the flow of water or waste materials containing water. For example, with regard to its proposal for a copper mine in Minnesota, USA, Twin Metals Minnesota (2021) writes, "Dry stacking filtered tailings means there is no need for a dam – dam failure is impossible." The response from the Minnesota Department of Natural Resources (2021) has been that a dam is a "structure that impounds water **and/or waste materials containing water**" (emphasis in the original). The Minnesota Department of Natural Resources (2021) further asked, "Is characterizing the tailings filter cake as being 'dry' a common terminology for a product exhibiting a 13% to 16% moisture content?" Klohn Crippen Berger (2017) has also emphasized that a filtered tailings facility "still requires 'structural zones' (which perform like dams), made of compacted tailings for confinement" and "if filtered tailings are placed in a stand-alone facility (pile/stack), the outer slopes must maintain structural stability (similar to a dam or a waste dump), particularly under seismic loading conditions." Finally, according to Safety First: Guidelines for Responsible Mine Tailings Management, "The structural zone of a filtered tailings facility is a type of tailings dam" (Morrill et al., 2020).

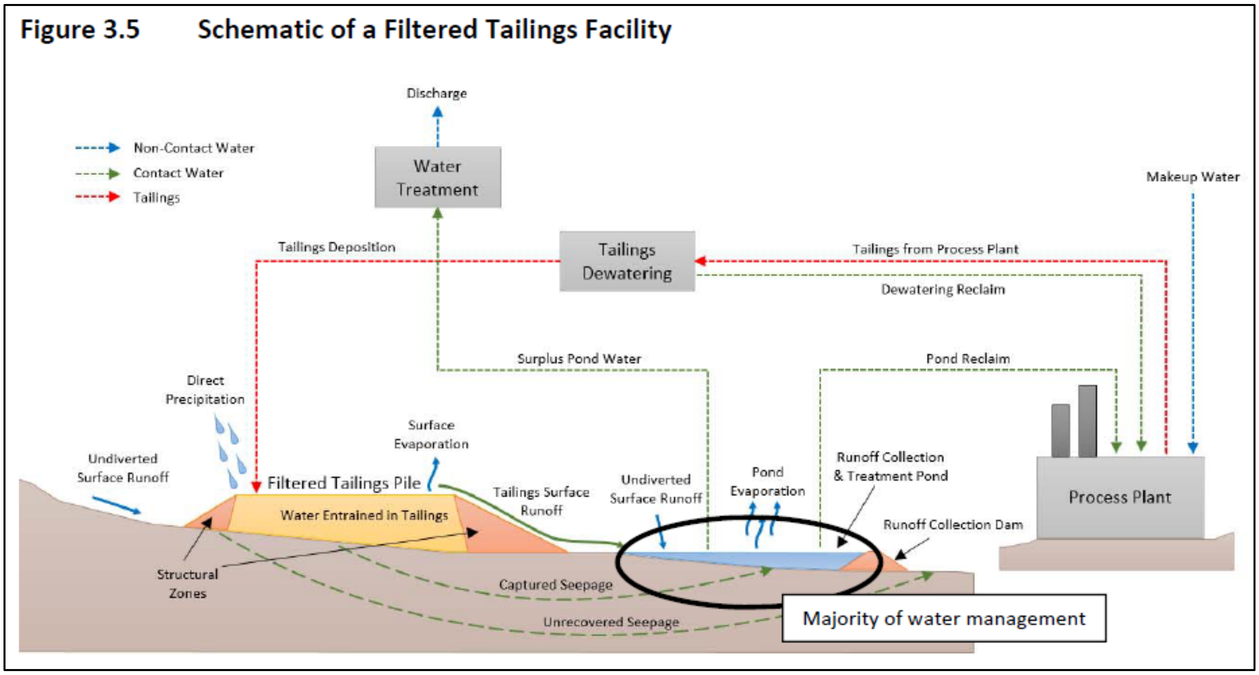

Figure 7. Based on current filter press technology, target water contents of 15% (typically required for adequate compaction) cannot be consistently met. Even if filtered tailings leave the filter presses with the target water content, they can be rewetted by precipitation. The standard response is to place the tailings that are too wet for adequate compaction in the center of the filtered tailings pile and to surround the wet tailings with "structural zones" constructed out of tailings that have the target water content for adequate compaction. The structural zone is a type of dam and should be designed to meet dam safety regulations. By contrast, the plans for the filtered tailings facility at the Dawson mine (Golder Associates, 2017; Environmental Alternatives, 2021a-b) never use the word "dam." Figure from Klohn Crippen Berger (2017).

The inner core of a filtered tailings storage facility is, in fact, a requirement for the storage of tailings that left the filter presses with too much water for adequate compaction. Crystal et al. (2018) have emphasized that target water contents for filtered tailings are rarely achieved. According to Crystal et al. (2018), "Commonly, projects are specifying (or promising) a target filter-cake moisture at the limit of the filter performance (including at the limit of the thickener's ability to deliver feed at the required solids ratio). This has caused numerous examples where the operating performance does not consistently meet the target … Essentially, irrespective of site, ore body type, or filter press manufacturer, a 15% moisture content remains a typical target, while tracking of day-in and day-out moisture contents of filter cakes demonstrates that achievable moisture contents are often in the range of 17 to 18% when things are running smoothly and can be up to 20 to 23% when off-spec … 'Targets' may be cited or promised, but achievable filter cake moisture contents and the variability of the process are not generally within the tailings engineer's control." For example, Mexican gold and silver mines that use filtered tailings technology have achieved moisture contents in the range 14-19% (Espinosa-Gomez et al., 2018). Even if the tailings leave the filter presses with the target water content, they can still be rewetted by precipitation. Thus far, these filtered tailings storage facilities have mostly been small and mostly constructed in areas with arid climates (Klohn Crippen Berger, 2017). The partial restriction to arid regions has partly been motivated by the greater need to recycle water in regions with high water scarcity. However, an additional factor has been the challenges in achieving the appropriate water content for adequate compaction in wet climates. At the present time, the standard solution in both arid and wet climates is to set aside an inner core (a region away from the outer slopes) for placement of tailings that cannot be adequately compacted. Crystal et al. (2018) continue, "The tailings engineer can, however, specify acceptable moisture contents for different areas of the dry stack, depending on stacking strategies. For example, external structural zones may have more stringent criteria than non-structural zones, for which reduced constraints may be allowed."

Although filtered tailings may be unsaturated when deposited in the tailings storage facility, it is still necessary to prevent resaturation of the tailings in order to prevent future liquefaction. The pore spaces between the tailing particles can become resaturated simply by consolidation under the weight of additional overlying tailings, which reduces the volume of pores so that they become filled with water (Klohn Crippen Berger, 2017). Water can also enter the filtered tailings storage facility through surface runoff, upward groundwater seepage, and direct precipitation onto the tailings. The above water sources require diversion canals that isolate the tailings storage facility from the rest of the watershed and appropriate drainage infrastructure for conveying any excess water out of the tailings.

It is important to point out that filtered tailings storage facilities have other possible failure mechanisms besides liquefaction. For example, surface runoff flowing over the structural zone could erode it away, thus exposing the uncompacted tailings that were behind the structural zone (see Fig. 7). Uneven settlement or failure of the foundation beneath the filtered tailings storage facility could cause failure of the entire structure. Finally, the structural zone (dam) could fail simply by sliding with no liquefaction or other flow behavior. According to Klohn Crippen Berger (2017), due to the typical low water content of filtered tailings, "Failure, if it occurs, would likely be local slumping and consequences would be restricted to the local area (or the distance equivalent to roughly 10 times the height [of the tailings dam]) … " On the other hand, flow behavior of the tailings could develop if the tailings mixed with sufficient water after dam failure. The above quote continues, " … unless the material slumps into a water body … When large water ponds are located downstream of high-density thickened/paste facilities, cascading failures are possible and should be accounted for when developing the risk profile of tailings failure management" (Klohn Crippen Berger, 2017). On the above basis, drainage and runoff collection ponds should be located sufficiently far downstream from the tailings dam and excessive accumulation of water in these ponds should be avoided (Klohn Crippen Berger, 2017; see Fig. 7).

Design Floods

Any tailings dam, including the structural zone of a filtered tailings storage facility, must be designed to resist a particular flood called the design flood. Without a knowledge of the design flood, there is no basis for determining the dimensions of the diversion canals or any other aspect of a tailings storage facility. Typically, the design flood depends upon the hazard potential or the consequences of the failure. In this section, three widely-recognized guidelines for determining design floods will be considered, which are the guidelines of the (U.S.) Federal Emergency Management Agency (FEMA, 2013), U.S. Army Corps of Engineers (USACE, 1991, 2014), and Canadian Dam Association (2013). All of the above guidelines refer to dams in general, rather than tailings dams in particular. The supplemental guidelines of the Canadian Dam Association (2019) consider the application of general dam safety guidelines to tailings dams. Two recent guidelines that seek recognition as global standards (Morrill et al., 2020;

ICMM-UNEP-PRI, 2020) will also be considered. Finally, the dam safety regulations in Colorado, which are not specific to tailings dams, will be taken into account.

The Federal Emergency Management Agency classifies dams in three categories according to the hazard potential (FEMA, 2013). High Hazard Potential means “probable loss of life due to dam failure or misoperation.” It is clarified that “probable loss of life” refers to “one or more expected fatalities” and that “economic loss, environmental damage or disruption of lifeline facilities may also be probable but are not necessary for this classification.” Significant Hazard Potential means “no probable loss of human life but can cause economic loss, environmental damage, or disruption of lifeline facilities due to dam failure or misoperation.” Low Hazard Potential means “no probable loss of human life and low economic and/or environmental losses due to dam failure or misoperation.”

Each of the classifications of hazard potential corresponds to an inflow design flood (FEMA, 2013). A dam with Low Hazard Potential must be designed for a 100-year flood (flood with a 1% exceedance probability in any given year) or “a smaller flood justified by rationale” (FEMA, 2013). A dam with Significant Hazard Potential should be designed for a 1000-year flood (flood with an exceedance probability of 0.1% in any given year). However, a dam for which failure is expected to result in the loss of at least one life (High Hazard Potential) must be designed for the Probable Maximum Flood (PMF), which is defined as “the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the drainage basin under study” (FEMA, 2013). The magnitude of the PMF is usually derived from the Probable Maximum Precipitation (PMP), which is defined as “the theoretical greatest depth of precipitation for a given duration that is physically possible over a particular drainage area at a certain time of year” (FEMA, 2013). It is worth noting that, according to the U.S. Army Corps of Engineers “the PMF does not incorporate a specific exceedance probability, but is generally thought to be well beyond the 10,000 year recurrence interval” (USACE-HCE, 2003).

In terms of design floods, the safety guidelines for dams designed by the U.S. Army Corps of Engineers are, in some cases, even stricter than those recommended by FEMA (2013). For all dams designed or maintained by the U.S. Army Corps of Engineers, “APF [Annual Probability of Failure] ≥ 1 in 10,000 (0.0001) Per Year. Annual probability of failure in this range is unacceptable except in extraordinary circumstances” (USACE, 2014). The U.S. Army Corps of Engineers has four categories of dam safety standards, similar to the three hazard potentials of the Federal Emergency Management Agency. The strictest “Standard 1 applies to the design of dams capable of placing human life at risk or causing a catastrophe, should they fail” (USACE, 1991). For this standard, “structural designs will be such that the dam will safely pass an IDF [Inflow Design Flood] computed from probable maximum precipitation (PMP) occurring over the watershed above the dam site” (USACE, 1991). For the third strictest Standard 3 dams, “the base safety standard will be met when a dam failure related to hydraulic capacity will result in no measurable increase in population at risk and a negligible increase in property damages over that which would have occurred if the dam had not failed” (USACE, 1991). For Standard 3 dams, “one-half of the PMF is the minimum acceptable IDF” (USACE, 1991).

The guidelines of the Canadian Dam Association (2013) include five dam classes, classified according to the consequences of failure. Risk to any permanent population places a dam in the three highest-consequence categories, in which the high-consequence, very high-consequence and extreme-consequence categories correspond to expected deaths of ten or less, 100 or less, and more than 100, respectively. Even with no permanent population at risk, the high-consequence category would apply if the consequences of failure included “significant loss or deterioration of important fish or wildlife habitat” or “high economic losses affecting infrastructure, public transportation and commercial facilities,” while the lesser significant-consequence category would apply only if the consequences involved “no significant loss or deterioration of fish or wildlide habitat” and “losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes” (Canadian Dam Association, 2013). The guidelines consider flood design criteria based on both a risk-informed approach and a traditional, standards-based approach. According to the risk-informed approach, the minimum annual exceedance probability of the design flood in the high-consequence category should be 1/2475 (corresponding to a return period of 2475 years), while the minimum annual exceedance probability in the very high- or extreme-consequence categories should be 1/10,000 (corresponding to a return period of 10,000 years). According to the traditional, standards-based approach, for a dam in the high-consequence category, the design flood should be 1/3 between the 1000-year flood and the PMF. For the very high-consequence category, the design flood should be 2/3 between the 1000-year flood and the PMF. For a dam in the extreme-consequence category, the design flood should be the PMF. The application to tailings dams follows the standards-based approach and makes the same recommendations (Canadian Dam Association, 2019).

The recent Safety First: Guidelines for Responsible Mine Tailings Management (Morrill et al., 2020) generally follows the guidelines of U.S. governmental agencies in calling for design for the PMF if there is potential loss of a single life and the 10,000-year flood (annual exceedance probability of 0.01%) otherwise. The even more recent Global Industry Standard on Tailings Management (GISTM) (ICMM-UNEP-PRI, 2020) is modeled on the Canadian Dam Association (2013, 2019) guidelines with five categories of dam failure consequences in which High, Very High, and Extreme refer to potential loss of 1-10, 10-100 and more than 100 lives, respectively. The high-consequence category also includes either “Significant loss or deterioration of critical habitat or rare and endangered species. Potential contamination of livestock/fauna water supply with no health effects” or “500-1,000 people affected by disruption of business, services or social dislocation. Disruption of regional heritage, recreation, community or cultural assets. Potential for short term human health effects” or “High economic losses affecting infrastructure, public transportation, and commercial facilities, or employment. Moderate relocation/compensation to communities.” According to ICMM-UNEP-PRI (2020), tailings dams in the high-consequence, very high-consequence, and extreme-consequence categories should be designed to withstand the 2475-year flood, the 5000-year flood, and the 10,000-year flood, respectively. Note the difficulty of comparing different design flood standards due to the varying uses of “potential,” “probable” and “expected” with respect to loss of life.

Although both of the above recent standards seek recognition as global standards, there is not yet any governmental regulatory agency that has adopted these standards. On the other hand, Morrill et al. (2020) has been endorsed by 142 civil society organizations, as well as a Spanish political party, and the International Council on Mining & Metals (ICCM) is expecting its 28 member companies to implement the GISTM by August 2023 (ICMM, 2020a; ICMM-UNEP-PRI, 2020). Neither Zephyr Minerals Ltd nor Zephyr Gold USA Ltd are member companies of ICMM, but it is noteworthy that Association Members include Canada Mining Innovation Council (CMIC), Mining Association of Canada (MAC), National Mining Association (NMA) – USA, Prospectors and Developers Association of Canada, World Gold Council, and Society for

Mining, Metallurgy, and Exploration (SME), which is based in Englewood, Colorado (ICMM, 2021).

Of course, the dam safety legislation in Colorado is the most relevant to a tailings dam in Colorado. The Office of the State Engineer Rules and Regulations for Dam Safety and Dam Construction (Code of Colorado Regulations, 2020) classifies dams into four categories, depending upon the consequences of dam failure. A High Hazard Dam is a dam "for which loss of human life is expected to result from failure of the dam. Designated recreational sites located downstream within the bounds of possible inundation should also be evaluated for potential loss of human life" (Code of Colorado Regulations, 2020). A Significant Hazard Dam is a dam "for which significant damage is expected to occur, but no loss of human life is expected from failure of the dam. Significant damage is defined as damage to structures where people generally live, work, or recreate, or public or private facilities" (Code of Colorado Regulations, 2020). A Low Hazard Dam is a dam "for which loss of human life is not expected, and significant damage to structures and public facilities … is not expected to result from failure of the dam." Finally, a No Public Hazard (NPH) Dam is a dam "for which no loss of human life is expected, and which damage only to the dam owner's property will result from failure of the dam" (Code of Colorado Regulations, 2020).

In the case of a large dam, the Colorado dam safety regulations require design for 90% of the Probable Maximum Precipitation (PMP) for a High Hazard Dam, 68% of the PMP for a Significant Hazard Dam, the 100-year precipitation event for a Low Hazard Dam, and even the 50-year precipitation event for a No Public Hazard Dam. A large dam is defined as a dam greater than 50 feet in height and/or having a storage capacity greater than 4000 acre-feet. The Colorado dam safety regulations allow alternative methods of computing the design flood in the terms of the Extreme Storm Precipitation (ESP) or the Site-Specific Extreme Storm Precipitation (SSESP) (Code of Colorado Regulations, 2020). Such level of detail is not necessary for this report because the important question is the applicability of the Colorado dam safety regulations to tailings dams.

The Colorado dam safety regulations define a dam as "a man-made barrier, together with appurtenant structures, constructed above the natural surface of the ground for the purpose of impounding water. Flood control and storm runoff detention dams are included" (Code of Colorado Regulations, 2020). Not all states define dams in such a restrictive way. For example, as mentioned earlier, Minnesota includes man-made structures that impound wet waste as dams (Minnesota Department of Natural Resources, 2021). In the case of the proposed Dawson gold mine, based on 546,531 US tons of moist tailings with a water content of 15%, the structural zone/dam of the filtered tailings storage facility would be impounding 81,980 US tons of water (equivalent to 67.7 acre-feet of water). However, the dam safety regulations explicitly exclude tailings dams by stating "Mill tailing impoundments which are permitted under the Colorado Mined Land Reclamation Act, sections 34-32-101 through 125, C.R.S. … are exempt from these Rules" (Code of Colorado Regulations, 2020).

The rules for Hard Rock Metal Mining (2 CCR 407-1) include essentially no prescriptive requirements for how tailings dams should be constructed and require only the submission of acceptable designs. According to Code of Colorado Regulations (2019), "If tailing ponds are part of the milling process, the mine plan description should address the following … Tailings: Describe the geochemical constituents of the tailing or leached ore, the chemistry of any leachate, anticipated impacts to ground or surface waters and design details such as liners, ponds and embankments, diversions or chemical treatment facilities to be used to control these impacts, and ground and surface water monitoring systems, to include proposed groundwater points of compliance." Nothing in the rules for Hard Rock Metal Mining implies that any and all designs would be acceptable. Therefore, the standards for acceptable designs could be specific to particular sites or mining projects in Colorado, but should be grounded in state, national and international guidelines for both tailings dams and water-retention dams.

SUMMARY OF DAWSON MINE

Water Balance

The most complete water balance for the proposed Dawson gold mine is found in the National Instrument 43-101 Technical Report for the Dawson Property, Colorado, USA (Golder Associates, 2017), the information that is provided to investors by mining companies that trade on the Toronto Stock Exchange (see Figs. 8a-b). In Fig. 8a of this report, larger numbers are overlain on the diagram from Golder Associates (2017) in order to emphasize the water inputs and outputs for the mining operation as a whole and for the filtered tailings storage facility (blue triangle on the lower right of Fig. 8a). According to the Technical Report, "The plant will require 135 gpm of process water to operate while over 90% recycle rate will minimize fresh water usage. It is estimated that the mine will supply 3.6 gpm of water in the form of ROM [Run of Mine] moisture and mine water, and 6.2 gpm of fresh water will be required for cooling, reagent mixing, process make-up, and potable water purposes throughout the plant" (Golder Associates, 2017). In the standard language of this report, the water use would be 135 gallons per minute, while the water consumption would be 9.8 gallons per minute (15.8 acre-feet per year). The diagram from the Technical Report (Golder Associates, 2017) clarifies that the 3.6 gallons per minute coming from the ore and the mine would include 1.1 gallons per minute from mine dewatering and 2.5 gallons per minute from water stored in fractures within the ore body (see Fig. 8a). The application further clarifies that the 6.2 gallons per minute of fresh water would be withdrawn from groundwater sources other than the groundwater that would flow into the mine. According to Environmental Alternatives (2021a), "The water supplies available to the property include 1) water dewatered from the mine and 2) a new water supply well to be constructed on the property … The new water supply well will provide water during the development stage. During mine operation, the water supply well and the dewatering of the mine will provide water to meet water demand. During mine operation, the process will mainly rely on the recycling of water with the water supply well used to top of the potable supply and the reclaim process water tank."

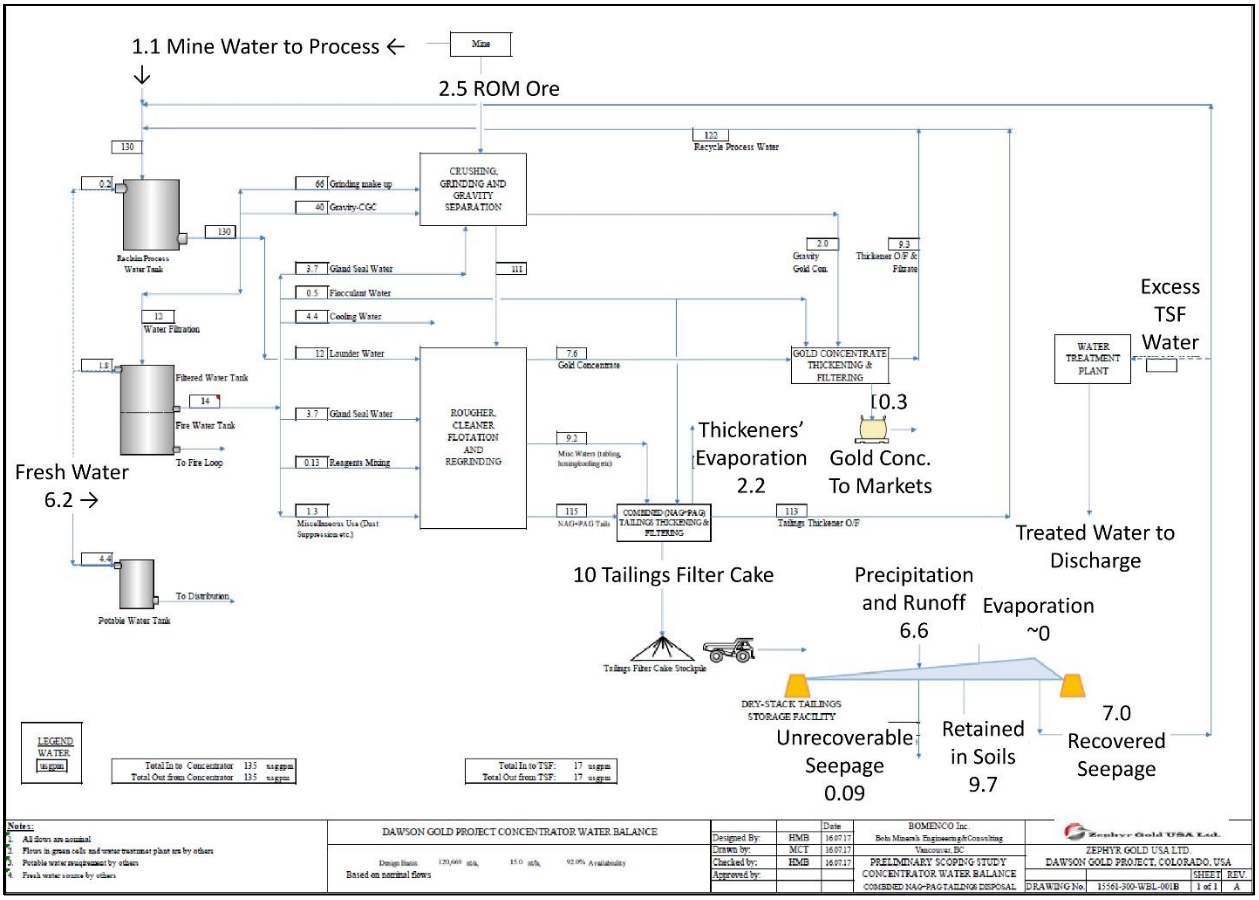

Figure 8a. The water balance diagram for the Dawson mine is overlain with larger numbers to emphasize inputs and outputs to the mine as a whole and to the filtered tailings facility (blue triangle in lower right). The inputs to the mine as a whole are water contained in the ore (2.5 gpm), water from dewatering the underground mine (1.1 gpm), fresh water from a supply well (6.2 gpm), and precipitation and runoff onto the filtered tailings facility (6.6 gpm). The outputs from the mine as a whole are evaporation from the tailings thickener and filter (2.2 gpm), water retained in the tailings (9.7 gpm), and water retained in the gold concentrate (0.3 gpm). Since the input (16.4 gpm) exceeds the output (12.2 gpm), 4.2 gpm should be regarded as the Excess TSF Water that must either evaporate from the contact water pond (see Figs. 7 and 9) or be treated and then discharged. The water consumption is the make-up water that must be withdrawn from surface water or groundwater sources. The predicted value (2.5 + 1.1 + 6.2 = 9.8 gpm) is an order of magnitude lower than what would be typical in the gold mining industry, even after taking into account the reduction in water consumption through the use of filtered tailings technology (see Figs. 16a-b and 17). None of the plans for the Dawson mine explain how such water efficiency would be achieved or even remark on its unusually high water efficiency (Golder Associates, 2017; Environmental Alternatives, 2021a-b). The most likely source of error is the very low evaporation rate (2.2 gpm) that is assumed for the mine as a whole. Based on an annual precipitation of 11.98 inches per year (Environmental Alternatives, 2021b) and surface area of 11.76 acres for the filtered tailings facility (measured from diagrams in Environmental Alternatives (2021b)), the precipitation onto the filtered tailings facility should be 7.3 gpm. The source of the 7.0 gpm of "Recovered Seepage" from the filtered tailings facility is unclear, since Environmental Alternatives (2021a) states "No liner system is included in the FTSF design based on the low seepage rates observed from compacted filtered tailings stacks" and "Seepage from the FTSF is expected to be negligible." Although the diagram shows a Water Treatment Plant before Treated Water to Discharge, the available documents do not include any plan for a water treatment plant. There is no mention of the possibility of water treatment for the water that is recycled through the mining operation and no analysis of the increase in the dissolved solids content of the process water that could occur due to recycling without treatment. In fact, saturation of the process water could result in precipitation of salts on all contact surfaces and in the tailings filter presses, which would render the filter presses non-functional. In addition, there is no discussion as to how the process water could still function to extract the gold concentrate with a high dissolved solids content. Figure modified from Golder Associates (2017).

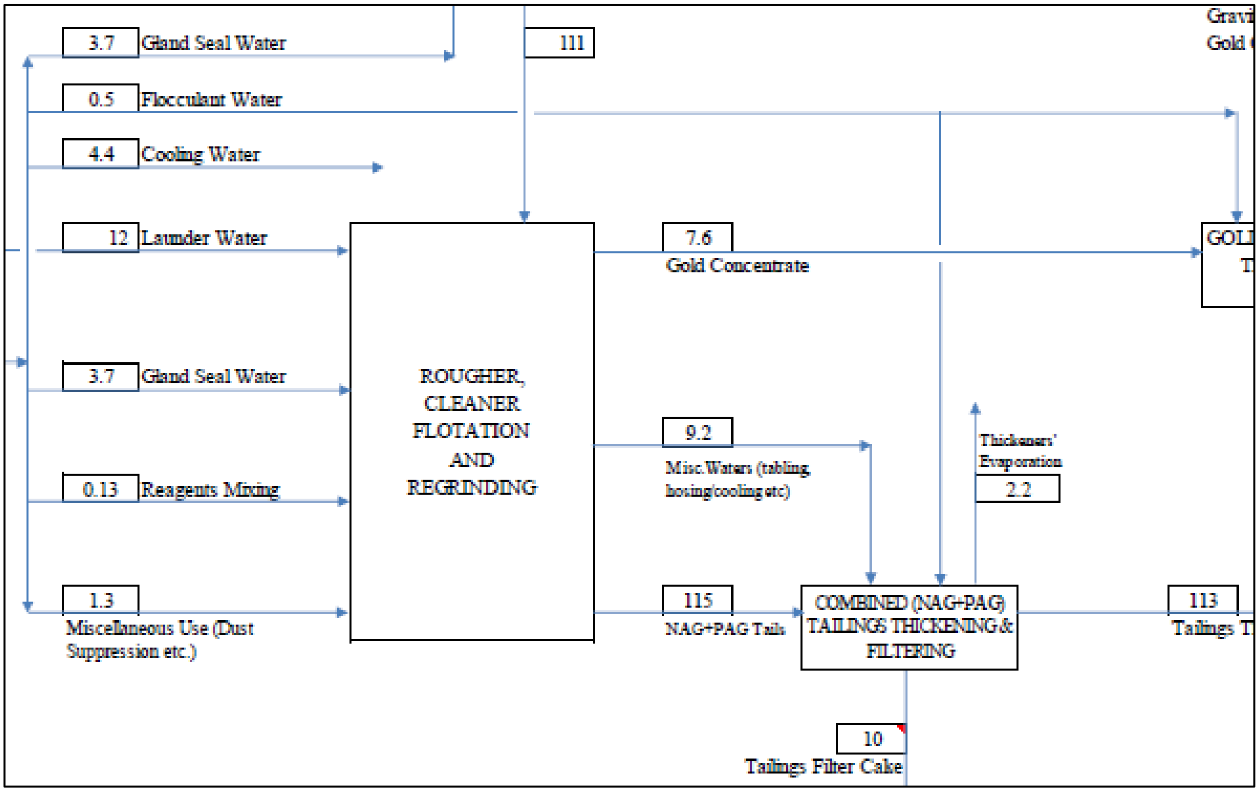

Figure 8b. A blow-up of a portion of the water balance diagram (see Fig. 8a) emphasizes the inputs and outputs to the boxes labeled "Rougher, Cleaner Flotation and Regrinding" and "Combined (NAG + PAG) Tailings Thickening & Filtering." The absurdity of the very low evaporation rate (and of assigning all evaporation to the tailings thickener) (see Fig. 8a) is also indicated by the assumption that there will be no evaporation of the water used for cooling (4.4 gpm) and dust suppression (1.3 gpm). Although the arrow labeled "Cooling Water" does not end anywhere (suggesting that it is lost to evaporation), both cooling water and water for dust suppression must enter the flotation and regrinding box in order to balance the inputs and outputs from the box. The inputs to the flotation and regrinding box are output from the box "Crushing, Grinding and Gravity Separation" (111 gpm), cooling water (4.4 gpm), launder water (12 gpm), gland seal water (3.7 gpm), reagents mixing (0.13 gpm), and miscellaneous use (dust suppression, etc.), totaling 132.53 gpm. The outputs from the flotation and regrinding box are gold concentrate (7.6 gpm), miscellaneous waters (tabling, hosing/cooling, etc.) (9.2 gpm), and NAG + PAG tails (115 gpm), totaling 131.8 gpm. The water balance is still not perfect (input exceeds output by 0.73 gpm), but evaporating the cooling water and dust suppression water before it enters the flotation and regrinding box would require the generation of 4.97 gallons per minute within the flotation and regrinding box. In the same way, the water balance assumes that the miscellaneous waters (including water for hosing and cooling) enter the tailings thickener box with no loss due to evaporation. The inputs to the tailings thickener box are miscellaneous waters (9.2 gpm), NAG + PAG tails (115 gpm), and flocculant water (0.5 gpm), totaling 124.7 gpm. The outputs from the tailings thickener box are tailings filter cake (10 gpm), tailings thickener O/F [overflow] (113 gpm) and thickeners' evaporation (2.2 gpm), totaling 125.2 gpm. Again, the water balance is not perfect (output exceeds input by 0.5 gpm), but evaporating the hosing/cooling water before it enters the tailings thickener box would require the generation of 9.7 gallons per minute within the tailings thickener box.

As is typical, although precipitation and runoff onto the filtered tailings (6.6 gallons per minute) is a water input, it is not counted as part of the water consumption rate (see Fig. 8a). The total water inputs (6.2 gpm from a supply well + 1.1 gpm from mine dewatering + 2.5 gpm from ore body moisture + 6.6 gpm from precipitation and runoff) would be equal to 16.4 gallons per minute. The total water outputs would include 2.2 gallons per minute as evaporation from the tailings thickeners, 9.7 gallons per minute as water entrained in the filtered tailings and then permanently retained within the tailings (labeled as "Retained in Soils" in Fig. 8a), and 0.3

gallons per minute entrained in the gold concentrate, adding to 12.2 gallons per minute (see Fig. 8). Since the projected input (16.4 gpm) exceeds the projected output (12.2 gpm), by design, the mining operation would release 4.2 gallons per minute into the environment. This excess water would be stored in the contact water pond prior to release (see Fig. 9). Some of this excess water may be lost by evaporation, although this amount has not been estimated. The excess water input could be even greater since, based on the average annual precipitation of 11.98 inches per year (Environmental Alternatives, 2021b) and the surface area of 11.76 acres for the filtered tailings storage facility (measured from maps in Environmental Alternatives (2021b)), the average water input by precipitation onto the filtered tailings facility should be 7.3 gallons per minute, not even counting the surface runoff that would flow into the contact water pond (see Fig. 9).

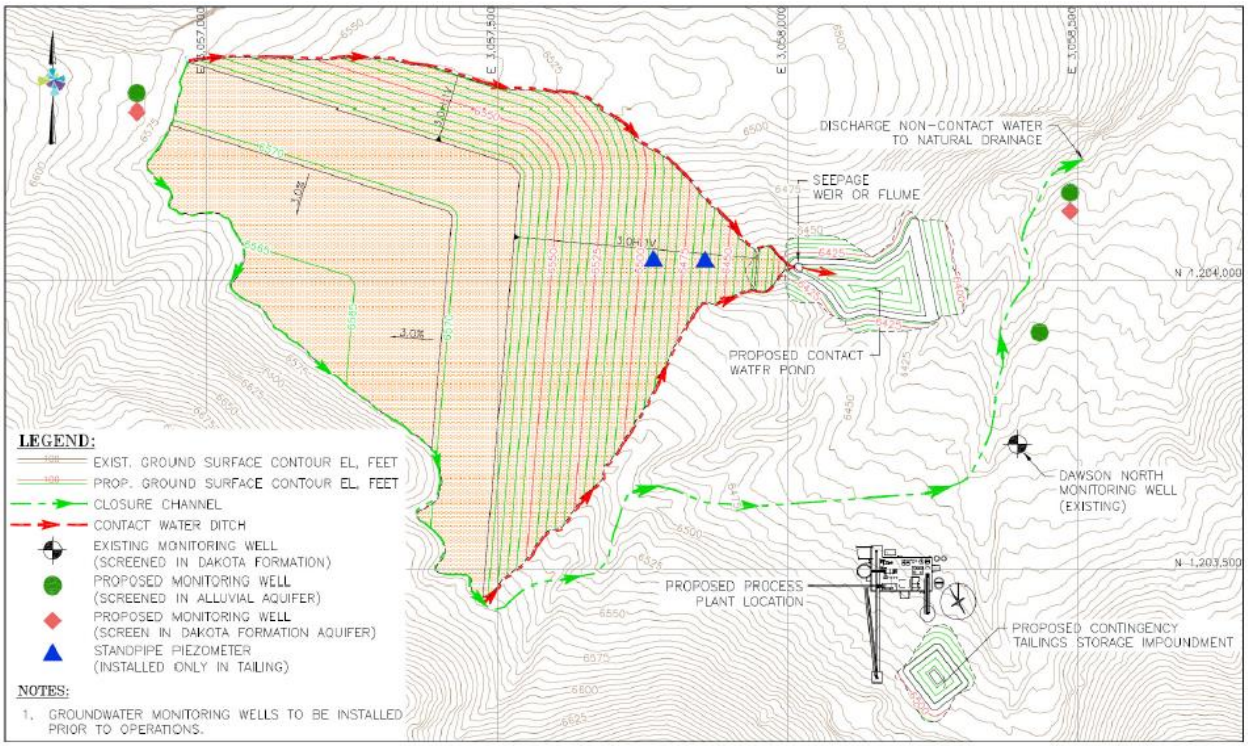

Figure 9. The filtered tailings facility would be constructed with diversion channels (contact water ditches) to prevent rewetting of the filtered tailings by surface runoff. The diversion channels would be designed to accommodate a 24-hour storm with a return period of 10 years during mine operation. On that basis, the probability of rewetting the tailings by runoff is 10% in any given year of mine operation and 41% over the five years of mine operation. Following mine closure, the diversion channels would be reconstructed to accommodate a 24-hour storm with a return period of 100 years, so that the probability of rewetting the tailings by runoff is 1% in any given year of the indefinite period of mine closure. There has been no analysis of the consequences of rewetting either in terms of dam stability or increasing the susceptibility of the tailings to liquefaction. Figure from Environmental Alternatives (2021b).

The mine dewatering that will be required by the flow of groundwater into the underground mine will inevitably result in the drawdown of surrounding groundwater. According to Environmental Alternatives (2021b), the dewatering of the underground mine would result in drawdowns as high as 285 feet on the mine property (see Fig. 10). Drawdowns greater than 5 feet in the hard rock would extend 1.1 miles from the mine property, while drawdowns greater than 5 feet in the sedimentary Dakota Formation would extend 0.9 miles from the mine property (see Fig. 10). It is noteworthy that the drawdown calculations do not depend upon the rate of mine dewatering, but only upon the groundwater elevation within the groundwater mine. Although the underground mine would extend to 1075 feet below the surface, the modeling carried out by Environmental Alternatives (2021b) set the groundwater elevation at 700 feet below the surface, under the assumption that hydraulic conductivity would be negligible below that depth. That assumption was based upon investigations in southern California at the Santa Susana Field Laboratory and by the U.S. Geological Survey in Death Valley (Environmental Alternatives, 2021b). Further information about the projected water balance and the effects of mine dewatering will be provided in the Results section.

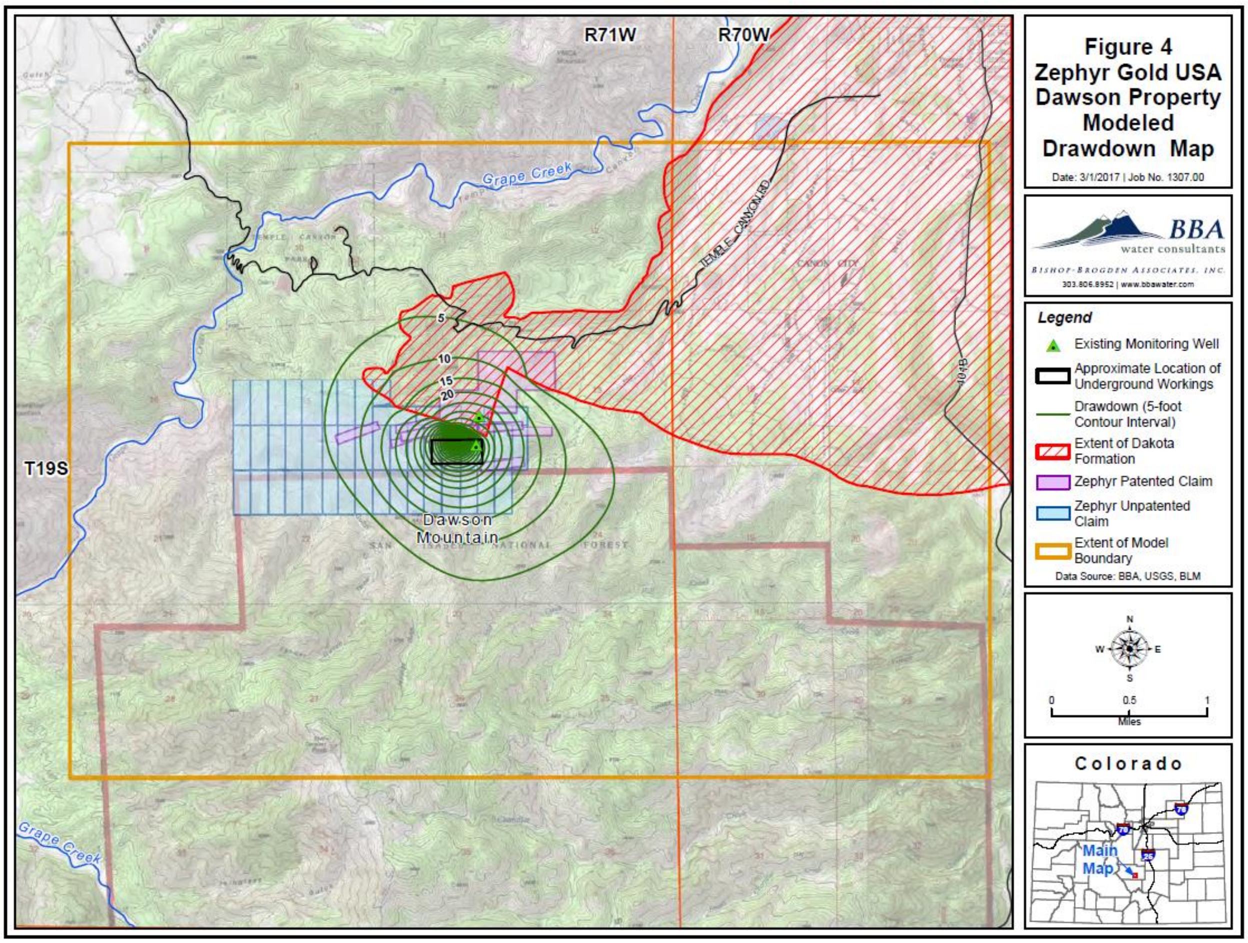

Figure 10. According to Environmental Alternatives (2021b), the dewatering of the underground mine would result in drawdowns as high as 285 feet at the mine location. Drawdowns greater than 5 feet in the hard rock would extend 1.1 miles from the mine location, while drawdowns greater than 5 feet in the sedimentary Dakota Formation would extend 0.9 miles from the mine location. Environmental Alternatives (2021b) calculated the drawdowns that would occur over 10 years and did not calculate the long-terms impacts of dewatering or the time required to restore the equilibrium of the groundwater system. Environmental Alternatives (2021b) also did not consider the additional drawdown that would result from pumping the fresh water supply well (see Fig. 8a).

Tailings Management

The application acknowledges that not all of the tailings would be successfully filtered to the target water content of 15% and that a structural zone would be necessary. According to Environmental Alternatives (2021b), "The feasibility of tailings filtration to the optimum moisture content (approximately) has not been proven for the Windy Gulch or Dawson tailings." Environmental Alternatives (2021b) then concludes, "A Shell Placement Zone, designated 'Zone 1', will be placed in the downstream shell of the FTSF to provide physical stability to the dry stack. A General Placement Zone, designated Zone 2 will be placed upstream of Zone 1 and will provide operational flexibility for tailings placement during periods of wet weather or upset filter plant conditions" (see Fig. 11). A comparison of Figs. 7 and 11 shows that "structural zone" and "shell placement zone" are exactly the same concept. The tailings in Zone 1 would be compacted to 105 pounds per cubic foot or 95% of the maximum tailings dry density of 111 pounds per cubic foot, as determined from measurements on tailings from the Windy Gulch ore deposit, while tailings in Zone 2 would be compacted to 100 pounds per cubic foot or 90% of the maximum tailings dry density (Environmental Alternatives, 2021b).

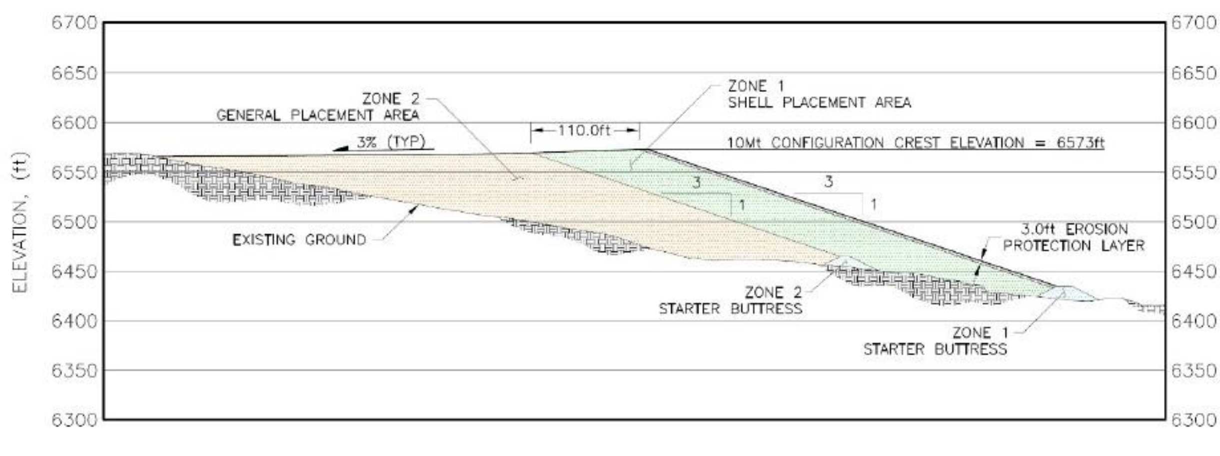

Figure 11. Tailings would be deposited into either Zone 1 (Shell Placement Area) or Zone 2 (General Placement Area), depending upon their water content. Tailings with an appropriate water content so that they can be compacted to 95% of their maximum density would be stored in Zone 1. Tailings that can be compacted to only 90% of their maximum density would be stored in Zone 2. Zone 1 constitutes a "structural zone," fulfills the same function as a dam, and should conform to dam safety regulations (see Fig. 7). The structural zone/dam would be constructed using the upstream method, in which the dam is built on top of the tailings that it is confining. In the event of the liquefaction of the tailings, the dam will collapse into the underlying tailings. For that reason, the method of upstream construction is illegal in Brazil, Chile, Ecuador and Peru. Figure from Environmental Alternatives (2021b).

The filtered tailings facility would be constructed with diversion channels (contact water ditches) to prevent rewetting of the filtered tailings by surface runoff (see Fig. 9). The diversion channels would be designed to accommodate a 24-hour storm with a return period of 10 years during mine operation (see Fig 9). Following mine closure, the diversion channels would be reconstructed to accommodate a 24-hour storm with a return period of 100 years (see Fig. 9). During mine operation, water in the diversion channels would flow into a contact water pond at the downslope base of the filtered tailings storage facility (see Figs. 7 and 9). The contact water pond would also act as the collection point for excess water from mine dewatering, precipitation onto the filtered tailings facility, and seepage from the filtered tailings facility (Environmental Alternatives, 2021b).

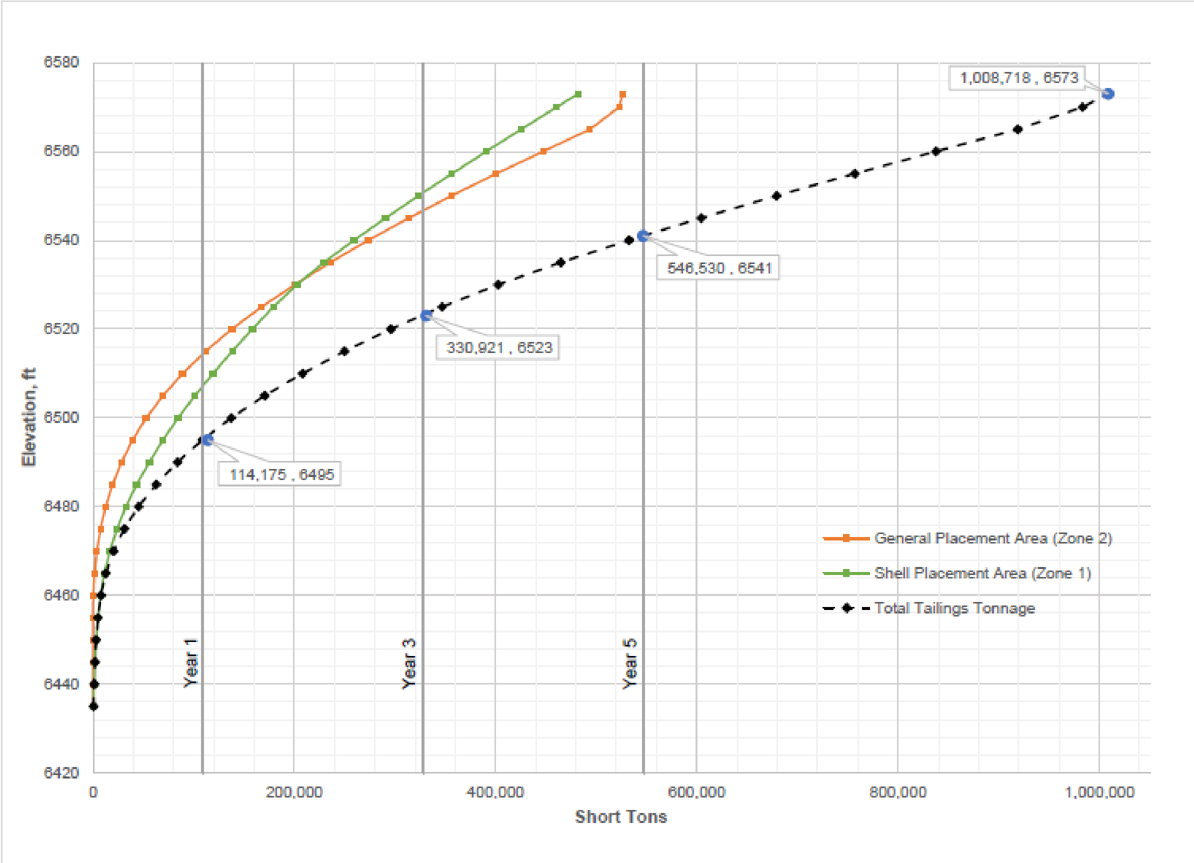

Figure 4: Tailings Stacking Curves for the Dawson FTSF

Figure 12. The documents related to the proposed Dawson gold mine (Golder Associates, 2017; Environmental Alternatives, 2021a-b) include numerous contradictions both internally and with one another. For example, the figure above shows elevations of the crest of the filtered tailings facility to be 6495 feet, 6523 feet, 6541 feet, and 6473 feet for the one-year, three-year, five-year, and ultimate configurations, respectively, corresponding to tailings dam heights of 75 feet, 103 feet, 121 feet, and 153 feet, respectively, based on a minimum elevation of 6420 feet (see Table 1 and Fig. 11). However, the seepage analysis was carried out assuming maximum tailings thicknesses of only 13 feet, 24 feet, 28 feet, and 38 feet, for the one-year, three-year, five-year, and ultimate configurations, respectively (see Fig. 15). Such low thicknesses cannot be reconciled with the above figure or Fig. 11 even if only vertically-measured distances are considered. No attempt was made to document all of the contradictions within the proposal documents. Figure from Environmental Alternatives (2021b).

The filtered tailings storage facility has been designed so that it could accommodate not only the 546,531 US tons of tailings resulting from five years of operation, but potentially 1,008,719 US tons of tailings (corresponding to roughly ten years of operation) (see Figs. 11-12). This “ultimate configuration” (Environmental Alternatives, 2021b) would have a crest elevation of 6473 feet, while the crest elevations of the filtered tailings facility would be 6495 feet, 6523 feet, and 6541 feet after one, three, and five years of operation, respectively (see Figs. 11-12). Based on a minimum elevation of 6420 feet for the filtered tailings facility (see Fig. 11), the tailings dam heights would be 75 feet, 103 feet, 121 feet, and 153 feet for the one-year, three-year, five-year, and ultimate configurations, respectively (see Table 1). The Code of Colorado Regulations (2020) clarifies that the jurisdictional height of a dam is defined as the difference between the elevation of the maximum normal water level at the spillway crest minus the lowest elevation of the base of the dam (see Fig. 13). As applied to the structural zone/dam of a filtered tailings storage facility (see Figs. 7 and 11), the maximum normal water level would correspond to the highest elevation of the filtered tailings.

Table 1. Scenarios for spill volume and runout following failure of the tailings facility[1]

Year	Dam Height[2] (ft)	Tailings Volume[3] (ac·ft)	Spill Volume (ac·ft)	Runout (ft)	
				Most-Likely	Worst-Case
1	75	51	19	4256	12,176
3	103	148	54	8526	25,851
5	121	245	86	11,905	37,098
Ultimate	153	452	154	18,273	58,876

[1]Spill volume and runout calculated using empirical formulae in Larrauri and Lall (2018). The worst-case scenario for runout assumes loss of 100% of stored tailings.
[2]Dam height calculated as the difference between the crest height (see Fig. 12) and a base height of 6420 feet (see Fig. 11).
[3]Tailings volumes calculated from masses given in Fig. 12 and assuming a density of 102.5 pounds per cubic foot.

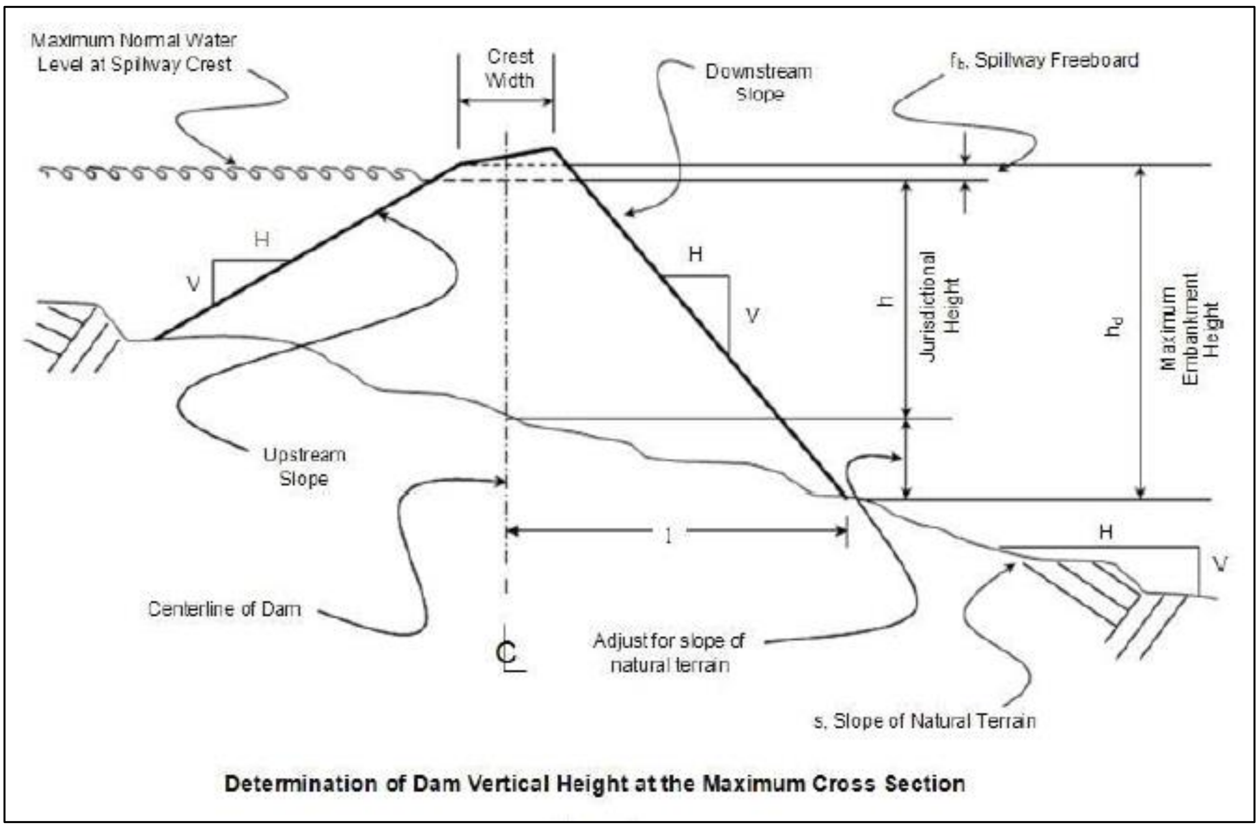

Figure 13. The above figure from Code of Colorado Regulations (2020) clarifies that the jurisdictional height of a dam is defined as the difference between the elevation of the maximum normal water level at the spillway crest minus the lowest elevation of the base of the dam. As applied to the structural zone/dam of a filtered tailings storage facility (see Figs. 7 and 11), the maximum normal water level would correspond to the highest elevation of the filtered tailings.

Table 2a. Colorado tailings dams sorted by height

Tailings Dam	Mine	Height (ft)	Current Storage (ac·ft)
Ten Pond #3 Dam[1]	Climax	416	152,703
Robinson[2]	Climax	387	124,039
Tenmile[2]	Climax	289	73,045
Upper URAD[2]	URAD	249	2675
Mayflower Pond #5[1]	Climax	237	64,300
Robinson Tailing Pond #1 Dam[1]	Climax	235	73,391
#1 Tailings Pond[1]	Climax	235	66,427
Mayflower[2]	Climax	213	31,310
Dawson gold mine (ultimate)[3]		**153**	**452**
Lower URAD[2]	URAD	141	5594
Dawson gold mine (5 years)[3]		**121**	**245**
Robinson[1]	Climax	110	3648
Telluride Tailings Pile 5-6[2]	Idarado	98	7702
Red Mountain Buried Tailings[2]	Idarado	98	unknown
Oregon Gulch Tailings Impoundment[2]	California Gulch	95	365
Iowa Gulch Tailings Impoundment[2]	Black Cloud	95	770
Summitville Tailings[1]	Summitville	83	450
Yak WTP Surge Pond[2]	California Gulch	75	unknown
Red Mountain #2[2]	Idarado	66	81
Dam 4[2]	Keystone	59	219
Dam 2[2]	Keystone	59	89
Robinson Tailing Pond #2 Dam[1]	Climax	52	13,000
Red Mountain #1[2]	Idarado	49	32
Red Mountain #3[2]	Idarado	49	81
Red Mountain #4[2]	Idarado	49	1216
Dam 1[2]	Keystone	46	32
Telluride Tailings Pile 1-4[2]	Idarado	43	178
Dam 3[2]	Keystone	30	65
Res #1 Tailings Pond[2]	California Gulch	unknown	unknown
Res #2 Tailings Pond[2]	California Gulch	unknown	unknown

[1]USACE (2021)
[2]GRID-Arendahl (2021)
[3]Calculated from data in Environmental Alternatives (2021a-b)

Based upon information in the Global Tailings Dam Portal (GRID-Arendahl, 2021) and the National Inventory of Dams (USACE, 2021), the tailings dam at the Dawson gold mine would be the ninth tallest tailings dam in Colorado at the five-year configuration and the eighth tallest tailings dam in Colorado at the ultimate configuration (see Table 2a). Based upon storage, the tailings dam at the Dawson gold mine would be the 14th and 16th largest tailings facilities in Colorado at the five-year and ultimate configurations, respectively (see Table 2b). There is some overlap in tailings dam names between the Global Tailings Dam Portal (GRID-Arendahl, 2021) and the National Inventory of Dams (USACE, 2021), but because the dam heights and storages were very different, they were listed as separate tailings dams (see Tables 2a-b). It is likely that the combination of the Global Tailings Dam Portal (GRID-Arendahl, 2021) and the National Inventory of Dams (USACE, 2021) is still an incomplete listing of all tailings dams in Colorado. The storage volume at the proposed Dawson gold mine was calculated by assuming a density of 102.5 pounds per cubic foot (halfway between the densities of Zone 1 and Zone 2).

Table 2b. Colorado tailings dams sorted by current storage

Tailings Dam	Mine	Height (ft)	Current Storage (ac-ft)
Ten Pond #3 Dam[1]	Climax	416	152,703
Robinson[2]	Climax	387	124,039
Robinson Tailing Pond #1 Dam[1]	Climax	235	73,391
Tenmile[2]	Climax	289	73,045
#1 Tailings Pond[1]	Climax	235	66,427
Mayflower Pond #5[1]	Climax	237	64,300
Mayflower[2]	Climax	213	31,310
Robinson Tailing Pond #2 Dam[1]	Climax	52	13,000
Telluride Tailings Pile 5-6[2]	Idarado	98	7702
Lower URAD[2]	URAD	141	5594
Robinson[1]	Climax	110	3648
Upper URAD[2]	URAD	249	2675
Red Mountain #4[2]	Idarado	49	1216
Iowa Gulch Tailings Impoundment[2]	Black Cloud	95	770
Dawson gold mine (ultimate)[3]		**153**	**452**
Summitville Tailings[1]	Summitville	83	450
Oregon Gulch Tailings Impoundment[2]	California Gulch	95	365
Dawson gold mine (5 years)[3]		**121**	**245**
Dam 4[2]	Keystone	59	219
Telluride Tailings Pile 1-4[2]	Idarado	43	178
Dam 2[2]	Keystone	59	89
Red Mountain #2[2]	Idarado	66	81
Red Mountain #3[2]	Idarado	49	81
Dam 3[2]	Keystone	30	65
Red Mountain #1[2]	Idarado	49	32
Dam 1[2]	Keystone	46	32
Red Mountain Buried Tailings[2]	Idarado	98	unknown
Yak WTP Surge Pond[2]	California Gulch	75	unknown
Res #1 Tailings Pond[2]	California Gulch	unknown	unknown
Res#2 Tailings Pond[2]	California Gulch	unknown	unknown

[1]USACE (2021)
[2]GRID-Arendahl (2021)
[3]Calculated from data in Environmental Alternatives (2021a-b)

The static stability analysis of the filtered tailings storage facility resulted in a factor of safety FS = 1.59 (see Fig. 14). The factor of safety is the minimum value of the ratio of the shear strength of the filtered tailings facility to the shear stress acting on the filtered tailings facility, as considered over all possible failure surfaces, so that FS = 1.0 indicates a tailings storage facility on the cusp of failure. The factor of safety is based upon the assumed densities and shear strength parameters (cohesion and friction angle) of the materials making up the filtered tailings facility and its foundation, as well as the assumed height of the water table within the filtered tailings facility (see Fig. 14). (The friction angle is called “phi” in Fig. 14). A static stability analysis and its corresponding factor of safety do not refer to the possibility of liquefaction, but to the tendency of the tailings storage facility to fail by slumping or sliding without liquefaction. The factor of safety FS = 1.5 is the minimum acceptable value of a factor of safety for tailings dams, according to most international standards (e.g, ANCOLD, 2012; Canadian Dam Association, 2013), and for embankment (earthen) dams in Colorado dam safety regulations (Code of Colorado Regulations, 2020).

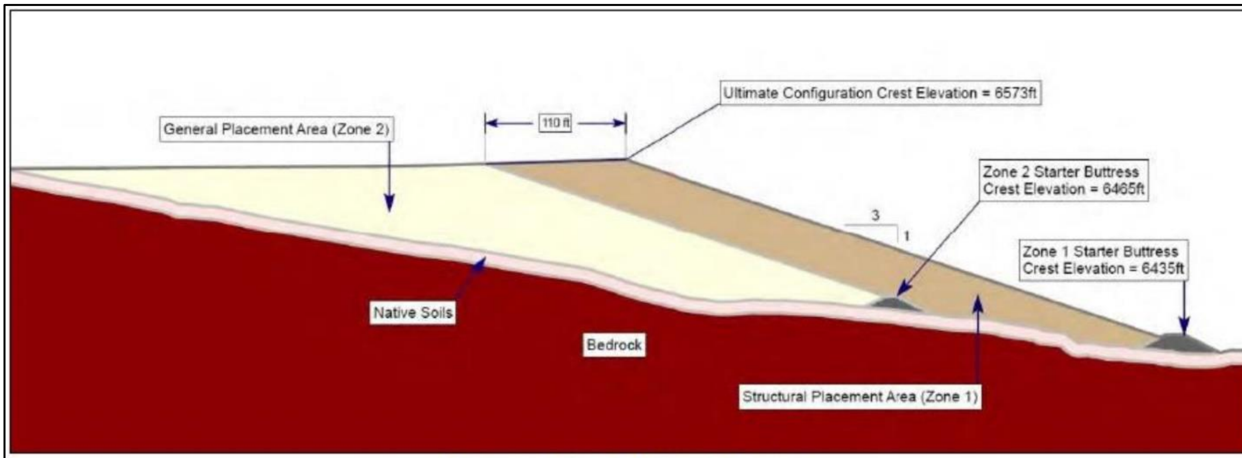

Figure 7: Typical Cross-Section

Table 13: Summary of Material Properties for Stability Analyses

Material	Moist Unit Weight	Effective Strength		Undrained Shear Strength Ratio
		Cohesion	Phi	
	(lb/ft³)	(psf)	(degrees)	(Su/σ_v')
Bedrock	125	0	40	--
Native Soils	115	0	28	--
Filtered Tailings (Zone 1)	105	0	32	--
Filtered Tailings (Zone 2)	100	--	--	0.35
Rockfill	122	0	32	--

Table 14: Results of Stability Evaluation

	Stability Analysis Factor of Safety	
	Circular Failure Surface	Non-Circular Failure Surface
Ultimate Configuration, Static	1.63	1.59
Ultimate Configuration, Pseudo-static	1.38	1.35

Figure 14. The static stability analysis of the filtered tailings facility resulted in a factor of safety FS = 1.59. The factor of safety is the lowest value of the ratio of the resistance of the tailings facility to failure by sliding to the shear stress acting on the tailings facility, as considered over all possible failure surfaces, so that FS = 1.00 indicates a tailings facility on the cusp of failure. The calculation of the factor of safety depends upon the geometry of the facility, the height of the water table, the densities (unit weights), and shear strength parameters (cohesion, phi, undrained shear strength ratio) of the materials making up the filtered tailings facility and its foundations. The moist unit weights were based on measurements of densities of tailings samples from a different ore deposit (Windy Gulch) and an assumed ability to compact the tailings to 95% and 90% of the maximum density in Zones 1 and 2, respectively. The same values stated for moist unit weights (which include the weight of entrained water) for tailings in the table above were stated as dry unit weights (which do not include the weight of entrained water) in the text of Environmental Alternatives (2021b). If the static stability analysis is using 100 and 105 pounds per cubic foot as moist unit weights when those values are actually dry unit weights, then the static stability analysis is underestimating the gravitational stress on the filtered tailings facility. For that reason alone, the calculation of the factor of safety would be an overestimate. All other parameters were assumed without justification. There was no mention of the assumed height of the water table or any discussion of the water table height that would result in dam instability or the circumstances under which such a water table height would occur. Figure is compilation of one figure and two tables from Environmental Alternatives (2021b).

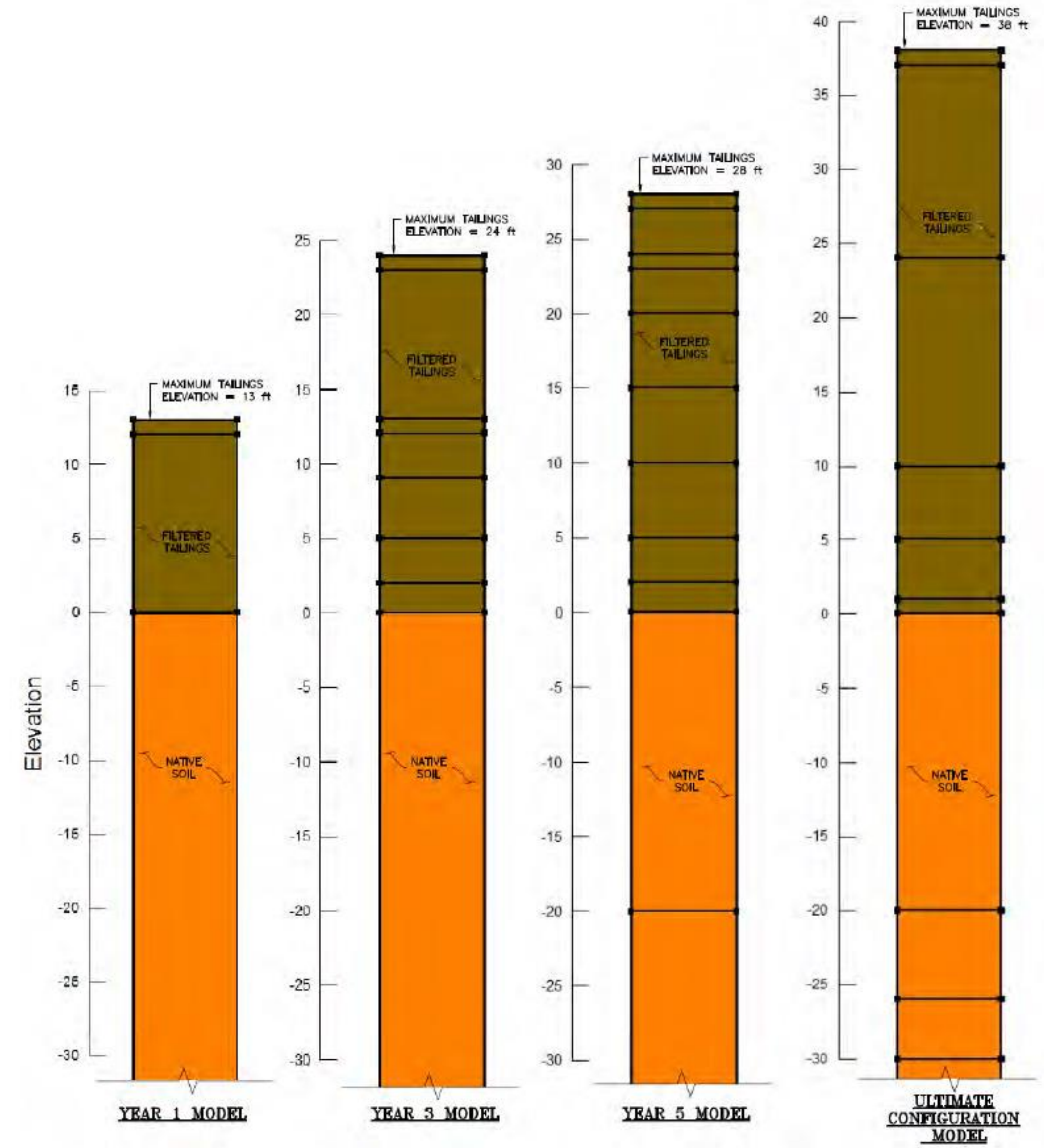

Figure 5: Seepage Models Schematic

Figure 15. The documents related to the proposed Dawson gold mine (Golder Associates, 2017; Environmental Alternatives, 2021a-b) include numerous contradictions both internally and with one another. For example, the seepage analysis in Environmental Alternatives (2021b) was carried out assuming maximum tailings thicknesses of only 13 feet, 24 feet, 28 feet, and 38 feet, for the one-year, three-year, five-year, and ultimate configurations, respectively. However, the same document shows elevations of the crest of the filtered tailings facility to be 6495 feet, 6523 feet, 6541 feet, and 6473 feet for the one-year, three-year, five-year, and ultimate configurations, respectively, corresponding to tailings dam heights of 75 feet, 103 feet, 121 feet, and 153 feet, respectively, based on a minimum elevation of 6420 feet (see Table 1 and Figs. 11 and 12). Such low tailings thicknesses cannot be reconciled with Figs. 11 and 12 even if only vertically-measured distances are considered. No attempt was made to document all of the contradictions within the proposal documents. Figure from Environmental Alternatives (2021b).

At this point, it is appropriate to point out that there are numerous contradictions both internally and among the various documents that have been provided by Zephyr Minerals Ltd (Golder Associates, 2017; Environmental Alternatives, 2021a-b). In particular, different numerical inputs are used for different types of analyses. As a single example, the tailings thicknesses assumed in the seepage analysis for the filtered tailings storage facilities were 13 feet, 24 feet, 28 feet, and 38 feet, for the one-year, three-year, five-year, and ultimate configurations, respectively (see Fig. 15). It is impossible to reconcile these very low tailings thicknesses with the tailings dam heights calculated above (see Figs. 11-12 and Table 1). The assumed tailings thicknesses cannot make sense even if they are regarded strictly as vertically measured distances (compare Figs. 11 and 15). On the basis of the seepage analysis, Environmental Alternatives (2021a) reported that “Seepage from the FTSF is expected to be negligible” so that “No liner system is included in the FTSF design based on the low seepage rates observed from compacted filtered tailings stacks.” The seepage analysis resulted in an average seepage rate of 0.7 gallons per minute in the five-year and ultimate configurations (Environmental Alternatives, 2021b), although the water balance diagram from Golder Associates (2017) states 7.0 gallons per minute as “Recovered Seepage” and 0.09 gallons per minute as “Unrecoverable Seepage” (see Fig. 8a). Golder Associates (2017) also states “Average seepage flows were estimated to be less than 1 gpm for the ultimate configuration of the FTSF.” No attempt was made in this report to document or reconcile all of the contradictions among the documents provided by Zephyr Minerals Ltd (Golder Associates, 2017; Environmental Alternatives, 2021a-b). Further information about the tailings management plan for the Dawson gold mine will be provided in the Results section.

METHODOLOGY

Following the preceding sections, the chief threat to groundwater is the impact of pumping from both the underground mine and the mine supply well, while the chief threat to both groundwater and surface water is the possibility of catastrophic failure of the filtered tailings storage facility. On that basis, the objective of this report can be subdivided into the following questions regarding the application (Environmental Alternatives, 2021a), its appendices (Environmental Alternatives, 2021b), and the Technical Report (Golder Associates, 2017):

1) Is there an adequate prediction of water consumption?
2) Is there an adequate prediction of the consequences of mine dewatering?
3) Is there an adequate plan for water treatment, both for the water that will be released from the mining operation and the water that will be recycled within the mining operation?
4) Is there an adequate analysis of the consequences of tailings dam failure?
5) Is there an adequate choice of design flood for the tailings dam?
6) Is there an adequate plan for the prevention of liquefaction of the filtered tailings?
7) Is there an adequate static stability analysis for the filtered tailings storage facility?
8) Does the filtered tailings storage facility include adequate water management infrastructure?

The first question was addressed by comparing the predicted water consumption rate with water consumption rates that are typical for the gold mining industry (see Table 3). Tost et al. (2018) is a good review of previous studies of water consumption in the gold mining industry. These studies have estimated unit water consumption either in terms of ore production, such as cubic meters of water per metric ton of ore (Mudd, 2007a, 2007b; Gunson, 2013; Department of

Water and Sanitation, 2016), or in terms of gold production, such as cubic meters of water per metric ton of gold (Mudd, 2007a, 2007b, 2010; Norgate and Haque, 2012, 2013; Gunson, 2013), or in terms of ore throughput, such as cubic meters of water per metric ton of ore as a function of metric tons of ore per year (Mudd, 2010). These gold industry averages were applied to the proposed Dawson gold mine by assuming an ore production of 330.8 US tons per day (365 days per year) and an ore grade of 9.2 grams of gold per metric ton of ore (Environmental Alternatives, 2021a).

Table 3. Average water consumption by gold mining

Study	Based on Ore Production (m^3 water / metric ton ore)	Based on Gold Production (m^3 water / metric ton gold)
Mudd (2007a)	1.42	691,000
Mudd (2007b)	0.88	325,000
Mudd (2010)		634,900
Norgate and Haque (2012)		259,290
Norgate and Haque (2012)[1]		288,140
Gunson (2013)	0.745	400,000
Northey and Haque (2013)		244,701
Northey and Haque (2013)[2]		284,235
DWS (2016)[3]	2.56	

[1]Norgate and Haque (2012) used two different methods.
[2]Norgate and Haque (2013) used two different methods.
[3]Department of Water and Sanitation (South Africa)

Unfortunately, there is no compilation of water consumption by gold mines that use filtered tailings technology or even of metallic mines that use filtered tailings technology. The available industry averages combine gold mines that do and do not use filtered tailings technology, as well as tailings ponds with varying evaporation rates (due to both varying atmospheric factors and varying technologies for controlling evaporation). As a first step, the industry averages were adjusted downward to account for filtered tailings technology by assuming that industry averages included no gold mines with filtered tailings facilities and the tailings ponds included in industry averages had zero net evaporation (or evaporation equal to precipitation and surface runoff). This first step was equivalent to reducing water consumption by 2 US tons of water for every 30 US tons of tailings (see subsection Filtered Tailings Technology for explanation) and was applied to the Dawson gold mine by assuming a tailings production rate of 14.4 US tons of tailings for every 18.4 US tons of ore (conversion of 78.3% of ore into tailings) (Golder Associates, 2017). The first step was a balanced adjustment because industry averages include some gold mines that use filtered tailings technology (so that the adjustment was too large) and some gold mines with tailings ponds with very high evaporation rates (so that the adjustment was too small). As a follow-up step, the industry averages were adjusted downward to account for filtered tailings technology by assuming that industry averages included no gold mines with filtered tailings facilities and the tailings ponds included in industry averages all had the maximum net evaporation rate (60% of all water loss in the tailings storage facility). This follow-up step was a considerable overadjustment and was equivalent to reducing water consumption by 12.5 US tons of water for every 30 US tons of tailings (see subsection Filtered Tailings Technology for explanation).

Since the documents from Zephyr Minerals Ltd (Golder Associates, 2017; Environmental Alternatives, 2021a-b) include no analysis of the consequences of tailings dam failure and do not even acknowledge that their plan includes a tailings dam, a preliminary analysis was carried out in this report. The analysis of consequences was based upon the most recent statistical model of past tailings dam failures (Larrauri and Lall, 2018). The statistical model predicts the volume of spilled tailings and the initial runout of tailings following dam failure. The initial runout is the distance covered by the tailings due to the release of gravitational potential energy as the tailings fall out of the tailings storage facility. After the cessation of the initial runout, normal fluvial processes could transport the tailings downstream indefinitely until the tailings reach a major lake or reservoir or the ocean. When the initial runout reaches a major river, as would happen in the failure of the tailings dam of the Dawson mine, it can be difficult to separate the initial runout from the subsequent normal fluvial processes. For example, the failure of the tailings dam at the Samarco mine in Minas Gerais, Brazil, spilled tailings into the Doce River, so that the initial runout extended 637 kilometers to the Atlantic Ocean (Larrauri and Lall, 2018).

According to Larrauri and Lall (2018), the best predictor of the initial runout of released tailings is the dam factor H_f, defined as

$$H_f = H\left(\frac{V_F}{V_T}\right)V_F \tag{1}$$

where H is the height of the dam (meters), V_T is the total volume of confined tailings and water (millions of cubic meters), and V_F is the volume of the spill (millions of cubic meters). The most-likely predictions for the volume of the spill and the initial runout D_{max} (kilometers) are then

$$V_F = 0.332 \times V_T^{0.95} \tag{2}$$

$$D_{max} = 3.04 \times H_f^{0.545} \tag{3}$$

It should be noted that Eqs. (2)-(3) express the most-likely consequences of dam failure. In particular, the most-likely consequence is that dam failure will result in the release of about one-third of the stored tailings (see Eq. (2)). However, the worst-case scenario is that dam failure will result in the release of 100% of the stored tailings, for which there are examples (Larrauri and Lall, 2018). Therefore, the worst-case runout ($V_F = V_T$) should be calculated using Eq. (3) with

$$H_f = HV_T \tag{4}$$

After computing the runout distance, the pathway of the tailings flood was constructed based on stream flowlines from the National Hydrography Dataset (USGS, 2021).

RESULTS

Adequacy of Prediction of Water Consumption

The projected water consumption for the Dawson gold mine (9.8 gpm) is far less than what would be predicted by using gold mining industry averages based on ore production, even after the first step in adjustment for the use of filtered tailings (see Fig. 16a). If the study by DWS (2016), which includes only South African gold mines, is removed as an outlier, the water consumption predicted by Zephyr Minerals Ltd is 18.5% of what would be predicted by the remaining three studies (53.0 gpm). In terms of the units used in published studies, the projected water consumption (9.8 gpm) would be equal to 0.18 cubic meters of water per metric ton of ore (compare with Table 3). The follow-up adjustment (a considerable overadjustment for the use of filtered tailings technology) would reduce the average of the water consumptions predicted by the remaining three studies to 37.9 gallons per minute. Even after this considerable overadjustment, the water consumption predicted by Zephyr Minerals Ltd is still only 25.8% of what would be predicted by published studies on water consumption by gold mines based on ore production.

The projected water consumption for the Dawson gold mine (9.8 gpm) is even lower when compared with what would be predicted by using gold mining industry averages based on gold production, starting with the first step in adjustment for the use of filtered tailings (see Fig. 16b). If the study by Mudd (2007a) is removed as an outlier, the water consumption predicted by Zephyr Minerals Ltd is 6.6% of what would be predicted by the remaining six studies (149.2 gpm). In terms of the units used in published studies, the projected water consumption (9.8 gpm) would be equal to 19,300 cubic meters of water per metric ton of gold (compare with Table 3). The follow-up adjustment (a considerable overadjustment for the use of filtered tailings technology) would reduce the average of the water consumptions predicted by the remaining six studies to 134.1 gallons per minute. Even after this considerable overadjustment, the water consumption predicted by Zephyr Minerals Ltd is still only 7.3% of what would be predicted by published studies on water consumption by gold mines based on gold production.

The very low projected water consumption by the Dawson gold mine (9.8 gpm) becomes still more unlikely when the small scale of the mine is considered. According to Mudd (2010), significant efficiencies in water consumption by gold mining do not occur below an ore throughput of about 3 million metric tons (Mt) per year or 9060 US tons per day (see Fig. 17). By contrast, the ore throughput of the Dawson gold mine would be 330.8 US tons per day (0.1095 million metric tons per year). Although there is considerable scatter in the data analyzed by Mudd (2010), the best-fit power relation between unit water consumption and ore throughput yields a water consumption rate of 110.8 gallons per minute or over 11.3 times the predicted water consumption for the Dawson gold mine (see Fig. 17). Taking into account the three comparisons (see Figs. 16a-b and 17), the projected water consumption by the Dawson gold mine is probably an order of magnitude too low, so that water consumption of at least 100 gallons per minute (160 acre-feet of water per year) would be a more reasonable projection.

It is now appropriate to revisit the water balance described in the Technical Report (Golder Associates, 2017) (see Fig. 8a). According to Golder Associates (2017), there will be zero evaporation from the filtered tailings facility (see Fig. 8a). In fact, the sole source of evaporation from the entire mining operation will be the evaporation from the tailings thickeners (2.2 gpm) (see Fig. 8a). The evaporation from an entire mining operation is not a simple calculation and it is usually back-calculated from the rate at which new water is withdrawn from groundwater and surface water sources. However, the assumption that the evaporation from the entire mining operation would be only 2.2 gallons per minute in the semi-arid climate of Colorado has not been justified in any document.

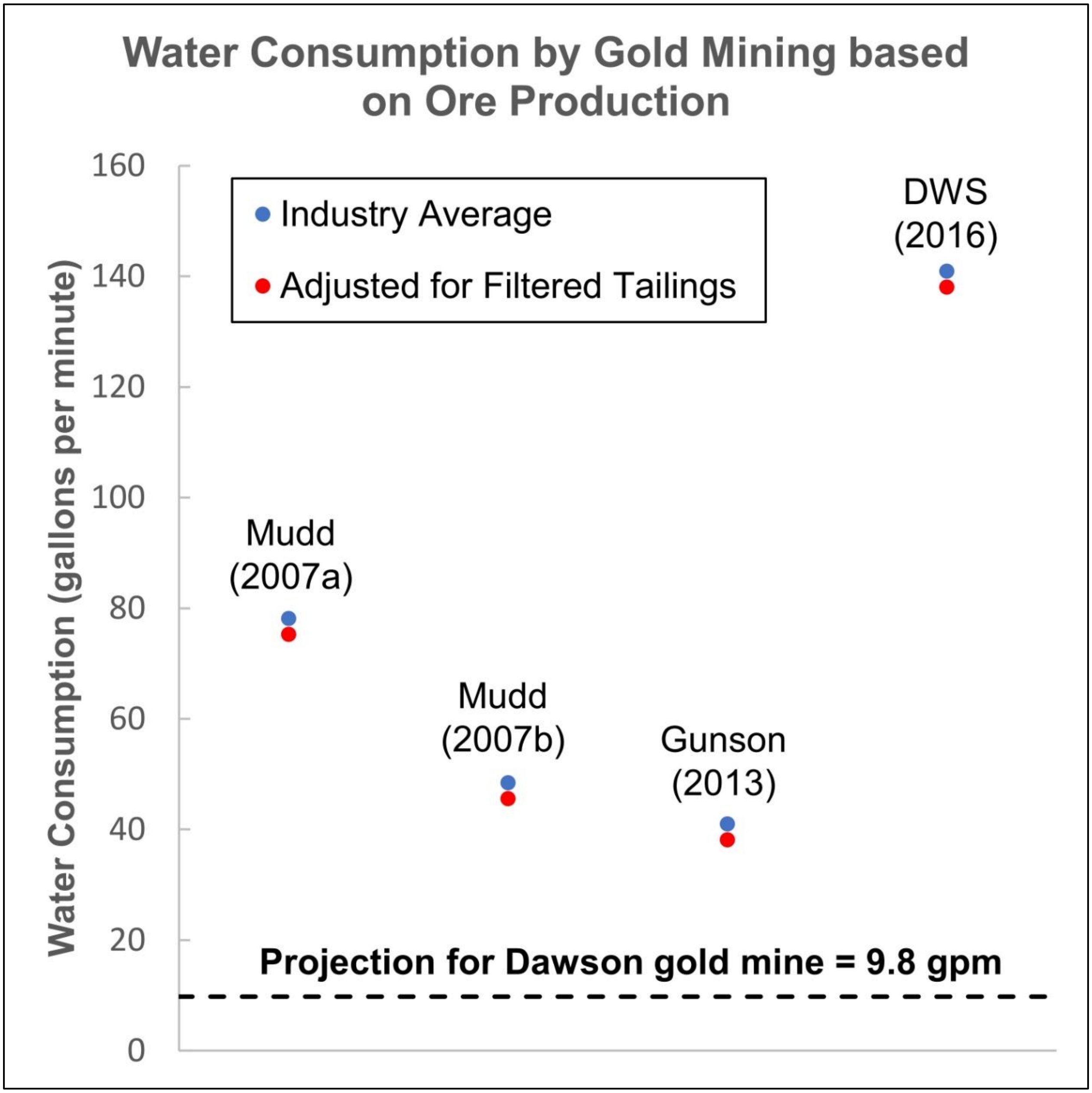

Figure 16a. In comparison with four studies of water consumption by gold mines based on ore production, the predicted water consumption for the Dawson gold mine (9.8 gpm) is far less than what would be typical in the gold mining industry, even taking into account the reduction in water consumption resulting from filtered tailings technology (see Table 3). If DWS (2016) is removed as an outlier, the predicted water consumption is 18.5% of the industry average after adjusting for filtered tailings. Industry averages were applied to the Dawson gold mine by assuming production of 330.8 US tons of ore per day with conversion of 78.3% of ore into tailings. Industry averages were adjusted for filtered tailings by subtracting 2 US tons of water for every 30 US tons of tailings (see Fig. 6).

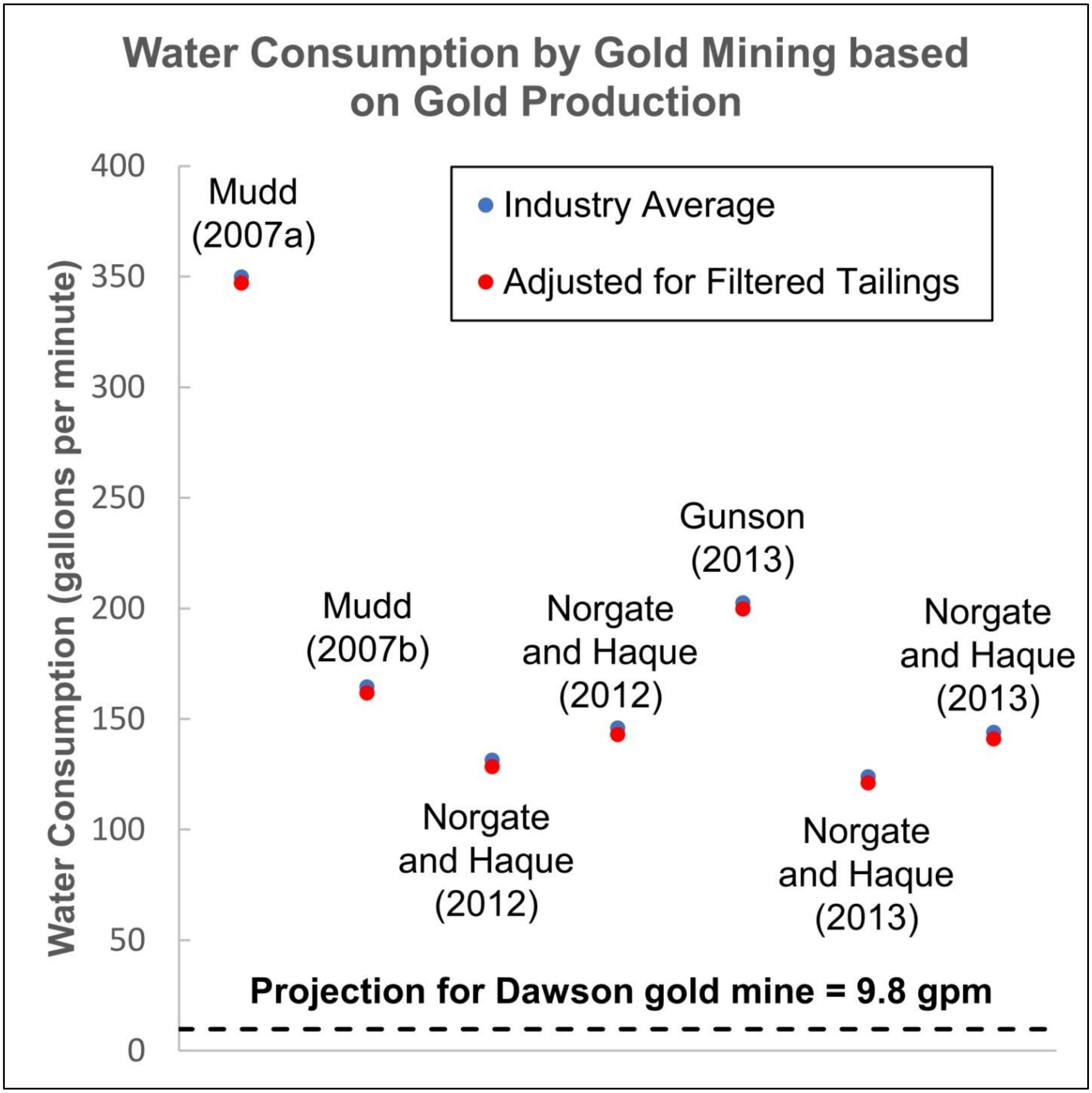

Figure 16b. In comparison with seven estimates (in five publications) of water consumption by gold mines based on gold production, the predicted water consumption for the Dawson gold mine (9.8 gpm) is far less than what would be typical in the gold mining industry, even taking into account the reduction in water consumption resulting from filtered tailings technology (see Table 3). If Mudd (2007a) is removed as an outlier, the predicted water consumption is 6.6% of the industry average after adjusting for filtered tailings. Industry averages were applied to the Dawson gold mine by assuming production of 330.8 US tons of ore per day with conversion of 78.3% of ore into tailings, and an ore grade of 9.2 grams of gold per metric ton of ore. Industry averages were adjusted for filtered tailings by subtracting 2 US tons of water for every 30 US tons of tailings (see Fig. 6).

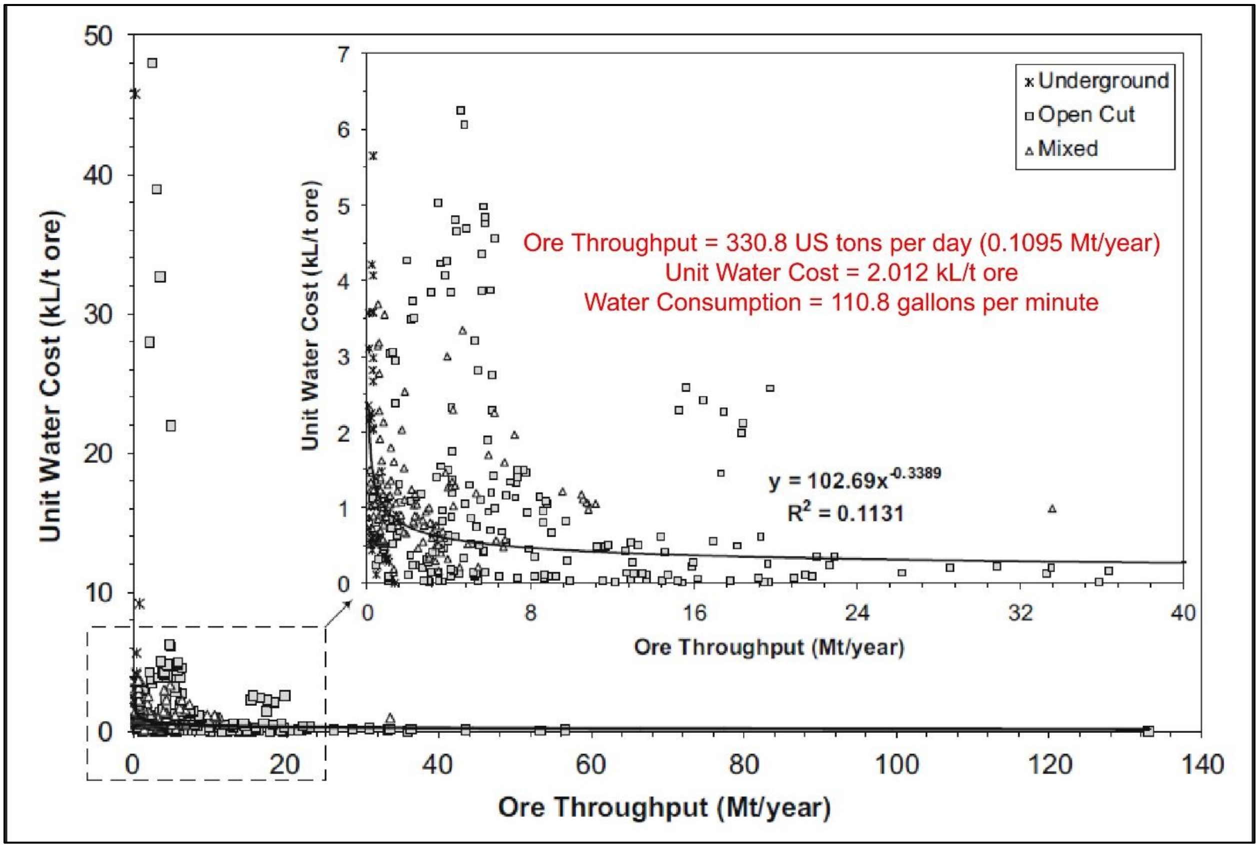

Figure 17. According to Mudd (2010), significant efficiencies in water consumption do not occur below an ore throughput of about 3 million metric tons (Mt) per year or 9060 US tons per day. By contrast, the ore throughput of the Dawson gold mine would be 330.8 US tons per day (0.1095 million metric tons per year). Although there is considerable scatter in the data, the best-fit power relation between unit water consumption and ore throughput yields a water consumption rate of 110.8 gallons per minute or over 11.3 times the predicted water consumption for the Dawson mine. Figure modified from Mudd (2010).

The absurdity of the very low evaporation rate (and of assigning all evaporation to the tailings thickener) is also indicated by the assumption that there will be no evaporation of the water used for cooling (4.4 gpm) and dust suppression (1.3 gpm) (see Fig. 8b). Although the arrow labeled "Cooling Water" does not end anywhere (suggesting that it is lost to evaporation), both cooling water and water for dust suppression must enter the box "Rougher, Cleaner Flotation and Regrinding" in order to balance the inputs and outputs from the box. The inputs to the flotation and regrinding box are output from the box "Crushing, Grinding and Gravity Separation" (111 gpm), cooling water (4.4 gpm), launder water (12 gpm), gland seal water (3.7 gpm), reagents mixing (0.13 gpm), and miscellaneous use (dust suppression, etc.), totaling 132.53 gpm (see Fig. 8b). The outputs from the flotation and regrinding box are gold concentrate (7.6 gpm), miscellaneous waters (tabling, hosing/cooling, etc.) (9.2 gpm), and NAG + PAG tails (115 gpm), totaling 131.8 gpm (see Fig. 8b). The water balance is still not perfect (input exceeds output by 0.73 gpm), but evaporating the cooling water and dust suppression water before it enters the flotation and regrinding box would require the generation of 4.97 gallons per minute within the flotation and regrinding box.

In the same way, the water balance assumes that the miscellaneous waters (including water for hosing and cooling) enter the box "Combined (NAG + PAG) Tailings Thickener & Filtering" with no loss due to evaporation (see Fig. 8b). The inputs to the tailings thickener box are miscellaneous waters (9.2 gpm), NAG + PAG tails (115 gpm), and flocculant water (0.5 gpm), totaling 124.7 gpm (see Fig. 8b). The outputs from the tailings thickener box are tailings filter cake (10 gpm), tailings thickener O/F [overflow] (113 gpm) and thickeners' evaporation (2.2 gpm), totaling 125.2 gpm (see Fig. 8b). Again, the water balance is not perfect (output exceeds input by 0.5 gpm), but evaporating the hosing/cooling water before it enters the tailings thickener box would require the generation of 9.7 gallons per minute within the tailings thickener box.

It is disturbing that nothing in the available documents (Golder Associates, 2017; Environmental Alternatives, 2021a-b) even remarks on the extremely low water consumption or discusses how such unprecedented water efficiency would be achieved. In the absence of further information, it should be assumed that actual water consumption will be much greater than projected and that the additional water will be provided by withdrawing much more water from a supply well than projected at the present time (6.2 gpm). Based on the preceding discussion, it is unlikely that the supply well will be pumped at only 6.2 gallons per minute and that a pumping rate on the order of 100 gallons per minute is much more likely.

Adequacy of Prediction of Consequences of Mine Dewatering

The groundwater impacts from the mining operation seem minor (Environmental Alternatives, 2021b), but they are based only upon the impact of dewatering of the underground mine and do not include the regional drawdown that could be caused by pumping the supply well. There is no information about the location or the depth of the supply well, so that it is not possible to calculate the additional drawdown due to the supply well. As explained in the previous subsection, a pumping rate on the order of 100 gallons per minute is much more likely. In summary, the actual groundwater impacts of the Dawson gold mine are entirely unknown at the present time.

It is also noteworthy that the groundwater impacts from mine dewatering were projected only for a 10-year period (Environmental Alternatives, 2021b). No attempt was made to calculate the long-term impacts of dewatering or the time required to restore the equilibrium of the groundwater system. According to Environmental Alternatives (2021b), "An isotropic hydraulic conductivity of 0.02 feet per day was used for the hard rock based on a review of limited well test data from State well completion reports and the potential range of fractured hard rock hydraulic conductivities." Such low hydraulic conductivities could mean that the filling of the underground excavation with groundwater could have only just begun at the end of the 10-year hydrogeologic modeling period. Since the underground excavation must eventually fill with water, the long-term regional drawdown of groundwater could extend for a considerable, but unknown, time into the future.

Adequacy of Plan for Water Treatment

Although the water balance diagram (see Fig. 8a) shows a "Water Treatment Plant" before "Treated Water to Discharge," the available documents do not include any plan for a water treatment plant, including no discussion of the contaminants that would need to be removed or how they would be removed. According to Environmental Alternatives (2021a), "Contact water in the contact water pond is expected to meet groundwater quality standards and, therefore, will not require treatment prior to discharge." However, the accompanying appendices state, “During operations contact water captured in the lined contact water pond will be recycled to the process plant. During this time, the water quality in the pond should be tested at least quarterly to provide a baseline characterization. Quarterly water monitoring at the contact water pond shall continue for a minimum period of 8 quarters post-closure. The required monitoring frequency and period after two years will be as negotiated with the regulatory agencies and will depend on further characterization of site specific conditions of the tailings, projected water quality and seepage rates” (Environmental Alternatives, 2021b). In other words, the main body of the application (Environmental Alternatives, 2021a) states categorically that no water treatment will be needed, while the appendices (Environmental Alternatives, 2021b) see the need for water treatment as a later decision to be decided based upon the results of water quality monitoring. At the same time, the appendices present no plan as to respond to the results of water quality monitoring. Although the appendices do not explicitly mention the possibility of water treatment, without such a possibility, it is difficult to understand the purpose of water quality monitoring and the anticipated negotiations with regulatory authorities.

In the application, Zephyr Minerals Ltd states an intention to obtain a National Pollutant Discharge Elimination System (NPDES) permit for the discharge of surface water. According to Environmental Alternatives (2021a), “Although the drainages at the mine are typically dry and best practices will be used to control sediment and discharges from the property including diversion channels, drainage ditches, culverts, sediment barriers and sediment ponds, a National Pollutant Discharge Elimination System (NPDES) Permit will be required in case discharges are made and the drainages do flow. Zephyr will acquire a NPDES permit from the Water Quality Control Division at the Colorado Department of Health and Environment before operations commence at the property. It would be acceptable for this to be a condition of approval.” Of course, applying for a permit and acquiring a permit are different concepts. In any event, based upon the present mining project application, the treatment of water prior to discharge from the contact water pond or other parts of the mine property seems to be a matter to be determined later, if necessary.

A matter of more immediate concern is that nowhere within the water circuit is there any plan for treatment of the water that is recycled within the mining operation, aside from sedimentation within the contact water pond and the passage of some water (12 gpm) through a water filtration system for storage in a filtered water tank (see Fig. 8a). The sedimentation and filtration would remove only solid particles, but not salts or dissolved solids. Sources of dissolved solids include the ore body and the various reagents and their degradation products. With no chemical water treatment, there could occur a long-term increase in the salinity or dissolved solids content of the process water as it recycles through the mining operation.

None of the available documents from Zephyr Minerals Ltd discuss in any way the implications of recycling without chemical water treatment. If the process water becomes saturated in any one of the possible salts, that salt will precipitate onto all contact surfaces, which could cause clogging in any part of the mining circuit. If the process water precipitates onto the pores of the filter presses, the presses will be rendered non-functional unless they can be continuously washed with fresh water. Of course, the water balance diagram includes no source of fresh water for continuous washing of the filter presses (see Figs. 8a-b). The most important matter of all is that it is not clear that the process water will continue to function for extraction of the gold concentrate once its dissolved solids content has risen high enough. The purpose here is not to argue that any of the preceding problems will actually occur, but to point out that the possibility of those problems has not even been discussed.

Adequacy of Analysis of Consequences of Dam Failure

Tailings dam failure scenarios were considered for the one-year, three-year, five year and ultimate configurations (see Table 1). For simplicity, maps of dam failure scenarios were based only on the five-year configuration (see Figs. 2-3) since the current application (Environmental Alternatives, 2021a-b) is proposing only five years of mine operation. Based on the statistical model of Larrauri and Lall (2018), the most-likely scenario is that the spill volumes will be 19 acre-feet, 54 acre-feet, 86 acre-feet and 154 acre-feet, corresponding, to 38%, 36%, 35%, and 34% of the stored tailings, for the one-year, three-year, five year and ultimate configurations, respectively (see Table 1). Based on the same model, the most-likely runout distances will be 4256 feet, 8526 feet, 11,905 feet and 18,273 feet for the one-year, three-year, five year and ultimate configurations, respectively (see Table 1). Under the worst-case scenario (loss of 100% of the stored tailings), the runout distances will be 12,176 feet, 25,851 feet, 37,098 feet, and 58,876 feet for the one-year, three-year, five year and ultimate configurations, respectively (see Table 1).

Under the most-likely scenario for the five-year configuration of the filtered tailings facility, dam failure will result in the initial transport of tailings over 2 1/4 miles down an unnamed tributary of Grape Creek, but not all the way to the confluence with Grape Creek (see Fig. 3). This initial runout will transport the tailings to within 740 feet of the municipal boundary of Cañon City and within 410 feet of the BLM Area of Critical Environmental Concern, assuming that all tailings transport is confined to the stream channel and that there is no overflow onto the banks (see Fig. 3). Subsequent normal fluvial processes will transport the tailings into Grape Creek and then into the Arkansas River (see Fig. 2). Under the worst-case scenario for the five-year configuration of the filtered tailings facility, dam failure will result in the initial transport of tailings over 7 miles to Grape Creek and then to the Arkansas River and through the center of Cañon City, while subsequent normal fluvial processes will transport the tailings indefinitely down the Arkansas River (see Fig. 2).

Adequacy of Design Flood

Since Zephyr Minerals Ltd does not recognize that the structural zone of the proposed filtered tailings storage facility would constitute a dam, none of the available documents (Golder Associates, 2017; Environmental Alternatives, 2021a-b) discuss the design flood or design precipitation event for the dam. Of course, Zephyr Minerals Ltd could design the filtered tailings facility to resist a particular flood or precipitation event in the same way that they can design the filtered tailings facility to resist a particular earthquake, even without using the word “dam.” It is difficult to choose the design flood without a rigorous analysis of the consequences of dam failure, which is not possible with presently-available information. However, the important questions are whether there is “potential” or “probable” or “expected” loss of human life in the event of dam failure and whether critical habitat is at risk.

Based on the most-likely scenario for dam failure (see Table 1 and Fig. 3), there does not seem to be potential loss of human life, since there do not appear to be any dwellings along the initial tailings flood path. On the other hand, the possibility of overbank flow across the municipal boundary of Cañon City is unknown. Moreover, under the definition of a High Hazard Dam, the Code of Colorado Regulations (2020) includes the statement “Designated recreational sites located downstream within the bounds of possible inundation should also be evaluated for potential loss of human life." Such designated recreational sites in the direct pathway of the most-likely tailings flood are possible, but they are not evident on the Cañon City, Colorado (2021) web site.

On the other hand, the worst-case scenario is truly frightening, since it will transport the tailings right through the center of Cañon City (see Fig. 2). As there is no discussion of the consequences of tailings dam failure, there is certainly no discussion of a warning system or an emergency evacuation plan for downstream residents. There have not been many measurements of the velocities of tailings flow slides, but they have ranged from 20-160 kilometers per hour (12-99 miles per hour) (Jeyapalan, 1981). According to Petley (2019), the tailings flow slide following the recent failure of the tailings dam near Brumadinho in Brazil in 2019 accelerated to 120 kilometers per hour (75 miles per hour) and then slowed to 66 kilometers per hour (41 miles per hour). As measured along the pathway of the tailings flood, the downstream edge of the filtered tailings facility is 24,418 feet from the municipal boundary of Cañon City (see Fig. 3). Based on the minimum velocity of 20 kilometers per hour, the tailings flood will cross the municipal boundary of Cañon City in about 22 minutes.

Such a short distance between a tailings dam and a downstream community would be prohibited in some countries that require a separation of at least 10 kilometers (over 6 miles). In response to the above-mentioned tailings dam disaster near Brumadinho, Brazil, the new tailings dam legislation in Brazil advanced the concept of the "self-rescue zone." Within the state of Minas Gerais, Brazil, it is prohibited to construct or expand a tailings dam where there is a population residing within the self-rescue zone. According to Assembleia Legislativa de Minas Gerais [Legislative Assembly of Minas Gerais] (2019), "*Fica vedada a concessão de licença ambiental para construção, instalação, ampliação ou alteamento de barragem em cujos estudos de cenários de rupturas seja identificada comunidade na zona de autossalvamento. § 1º – Para os fins do disposto nesta lei, considera-se zona de autossalvamento a porção do vale a jusante da barragem em que não haja tempo suficiente para uma intervenção da autoridade competente em situação de emergência. § 2º – Para a delimitação da extensão da zona de autossalvamento, será considerada a maior entre as duas seguintes distâncias a partir da barragem: I – 10km (dez quilômetros) ao longo do curso do vale; II – a porção do vale passível de ser atingida pela onda de inundação num prazo de trinta minutos. § 3º – A critério do órgão ou da entidade competente do Sisema, a distância a que se refere o inciso I do § 2º poderá ser majorada para até 25km (vinte e cinco quilômetros), observados a densidade e a localização das áreas habitadas e os dados sobre os patrimônios natural e cultural da região"* [It is forbidden to grant an environmental license for the construction, installation, expansion or elevation of a dam for which studies of rupture scenarios identify a community in the self-rescue zone. § 1 – For the purposes of the provisions of this law, the portion of the valley downstream of the dam in which there is not enough time for intervention by the competent authority in an emergency situation is considered a self-rescue zone. § 2 – For the delimitation of the extent of the self-rescue zone, the greatest between the following two distances from the dam will be considered: I – 10 km (ten kilometers) along the course of the valley; II - the portion of the valley that can be reached by the flood wave within thirty minutes. § 3 - At the discretion of the competent body or entity of SISEMA, the distance referred to in item I of § 2 may be increased to up to 25 km (twenty-five kilometers), taking into account the density and location of the inhabited areas and the data on the region's natural and cultural heritage]. Although not stated, the generally accepted minimum tailings flow velocity of 20 kilometers per hour is the apparent basis for the equivalence between 10 kilometers and 30 minutes.

Ecuador adopted the same concept the following year. According to Ministerio de Energía y Recursos Naturales No Renovables [Ministry of Energy and Non Renewable Natural Resources] (Ecuador) (2020a), "*Se prohíbe el diseño y construcción de depósitos de relave en los casos que se identifique una zona poblada ubicada aguas abajo del mismo que pudiera ser afectada por la onda de inundación, la cual queda limitada por la mayor de las dos distancias: • A diez (10) kilómetros de distancia aguas abajo del pie de la presa a lo largo del curso del valle, o; • La porción de territorio que sea alcanzada por la onda de inundación en un plazo de 30 minutos*" [The design and construction of tailings deposits is prohibited in cases where a populated area located downstream of the same is identified that could be affected by the flood wave, which is limited by the greater of the two distances: • Up to ten (10) kilometers downstream from the toe of the dam along the course of the valley, or; • The portion of territory that could be reached by the flood wave within 30 minutes]. Morrill et al. (2020) critiqued the above distances and arrival times in writing, "Although these limits can be seen as progress compared to a lack of any regulation, they are arbitrary and will not necessarily ensure safe evacuation in every situation. Therefore, minimum distance between communities and new dams must be defined on a case-by-case basis."

Based on the preceding discussion, the prudent choice would be to regard the filtered tailings facility at the Dawson gold mine as a High Hazard Dam, using the Colorado dam classification system, for which the primary definition is a dam "for which loss of human life is expected to result from failure of the dam" (Code of Colorado Regulations, 2020). Following Colorado dam safety regulations, since the filtered tailings facility would be classified as a large dam (height exceeding 50 feet), the design precipitation event should be 90% of the Probable Maximum Precipitation (PMP). Following the standards of the Federal Emergency Management Agency, the filtered tailings facility should be designed to withstand the Probable Maximum Flood (PMF), since it would be a High Hazard Potential Dam with "probable loss of life due to dam failure or misoperation" (FEMA, 2013). Following the standards of the U.S. Army Corps of Engineers, the filtered tailings facility should be designed to withstand the flood resulting from the PMP based on Standard 1 that "applies to the design of dams capable of placing human life at risk or causing a catastrophe, should they fail" (USACE, 1991). Following the standards of Safety First: Guidelines for Responsible Mine Tailings Management, the filtered tailings facility should be designed to withstand the PMF since it would be a "dam whose failure would result in the potential loss of a single life" (Morrill et al., 2020).

It is more problematic to apply the standards of the Canadian Dam Association or the GISTM, since the consequence categories depend upon the number of potential or expected deaths, which are difficult to estimate without more rigorous analysis in the case of the Dawson gold mine. However, the high-consequence category of the Canadian Dam Association (corresponding to expected deaths of ten or less) also includes "significant loss or deterioration of important fish or wildlife habitat" (Canadian Dam Association, 2013). Considering the proximity of the filtered tailings facility to Cañon City and a BLM Area of Critical Environmental Concern (see Figs. 2-3), the high-consequence category seems appropriate at a minimum, which requires the design of the tailings dam to withstand a flood with magnitude 1/3 between the 1000-year flood and the PMF (Canadian Dam Association, 2019). In a similar way, the high-consequence category of the GISTM (corresponding to potential loss of 1-10 lives) includes "significant loss or deterioration of critical habitat" and requires design to withstand the 2475-year flood (ICMM-UNEP-PRI, 2020).

In summary, by Colorado dam safety standards, the filtered tailings facility should be designed to withstand 90% of the Probable Maximum Precipitation (PMP). By the standards of the Federal Emergency Management Agency, the U.S. Army Corps of Engineers, and Safety First: Guidelines for Responsible Mine Tailings Management, the filtered tailings facility should be designed to withstand the Probable Maximum Flood (PMF) (the flood corresponding to the PMP). By the standards of the Canadian Dam Association, the filtered tailings facility should be designed to withstand a flood at least 1/3 between the 1000-year flood and the PMF. By the standard of the Global Industry Standard for Tailings Management, the filtered tailings facility should be designed to withstand at least the 2475-year flood. The concept of a design flood or precipitation event is not mentioned in any of the documents from Zephyr Minerals Ltd.

Adequacy of Plan for Prevention of Liquefaction

The documents from Zephyr Minerals Ltd do not include any discussion of the circumstances under which liquefaction of the filtered tailings could occur. According to Environmental Alternatives (2021b), "The Dawson tailings will be compacted to an unsaturated state of 95% of the standard Proctor maximum dry density in the perimeter shell. Such densely compacted tailings will dilate, or increase in volume, when sheared, essentially resulting in a decrease in pore water pressures, therefore tailings in the perimeter shell are not considered to be susceptible to liquefaction." However, even after the initial compaction of the tailings, it is still necessary to consider possible sequences of events under which the tailings could become resaturated through precipitation or surface runoff or by the weight of overlying tailings. Moreover, the most important consideration is not the possible liquefaction of the tailings making up the structural zone/dam, but the possible liquefaction of the lightly-compacted tailings that would be confined by the structural zone/dam (see Fig. 11). In this respect, there has not even been any consideration as to the particle size distribution of the tailings, which would be a starting point toward evaluation as to whether the tailings would be susceptible to liquefaction. As mentioned earlier, tailings with a mix of fine and coarse particles will tend to be susceptible to liquefaction, since the finer particles will fill the spaces between the coarser particles and prevent the escape of water during deformation.

Since the possibility of liquefaction of the lightly-compacted tailings in Zone 2 General Placement Area cannot be dismissed without further investigation, it is important to note that the structural zone (the dam) would be constructed on top of the lightly-compacted tailings (see Fig. 11), which is known as the method of upstream construction. The method of upstream construction is the cheapest method of dam construction because it uses the minimum amount of construction material (in the case of the Dawson mine, tailings with an appropriate water content for adequate compaction). On the other hand, the method of upstream construction is the most dangerous because, if the underlying tailings undergo liquefaction, the dam will simply fall backwards and downwards into the liquefied tailings, even if the dam itself does not liquefy. For this reason, the method of upstream construction for tailings dams is illegal in Brazil (Agência Nacional de Mineração [National Mining Agency], 2019), Chile (Ministerio de Minería (Chile) [Ministry of Mining (Chile)], 2007), Ecuador (Ministerio de Energía y Recursos Naturales No Renovables (Ecuador), 2020b) and Peru (Sistema Nacional de Información Ambiental (Perú) [National System of Environmental Information (Peru)], 2014).

Adequacy of Static Stability Analysis

Although the static stability analysis indicates an acceptable factor of safety (FS > 1.5), the stability analysis was not based upon any measurements of the actual materials that would make up the filtered tailings storage facility or its foundation (see Fig. 14). The only explanation for the choices of parameters was the statement "The unit weight of the structural and general placement areas were derived from Proctor tests and based on the design criteria stating that the shell and general placement areas must be 95% and 90% of the standard Proctor maximum dry density, respectively. All materials, except for the zone of general placement filtered tailings (Zone 2), were assigned effective strength (i.e., drained) properties. The general placement tailings were conservatively assigned an undrained shear strength ratio (S_u/σ'_v) of 0.35." There was no explanation for the choices of any of the shear strength parameters or any of the properties of the bedrock, native soils or rockfill. Moreover, the unit weights (densities) were obtained from tailings from a different ore deposit, not the deposit that would be extracted by the Dawson gold mine. According to Environmental Alternatives (2021b), "For this study, one composite synthetic tailings sample was generated from 60 core samples obtained from exploration drilling of the Windy Gulch deposit. Geotechnical classification testwork and geochemical characterization were conducted on the tailings sample. As no tailings sample was available from the Dawson Segment, the properties of the Windy Gulch tailings sample were assumed for the design of the FTSF."

The Summary of Material Parameters for Stability Analyses in Environmental Alternatives (2021b) refers to the values of 105 and 100 pounds per cubic foot for the filtered tailings in Zones 1 and 2, respectively, as the moist unit weight, meaning that the weight includes the weight of the entrained water (see Fig. 14). However, the same document repeatedly refers to the same values as dry densities or dry unit weights, meaning that the weights do not include the weight of entrained water. For example, Environmental Alternatives (2021b) states "Specifically, the following assumptions and design criteria were applied: In-place tailings dry density = 105 pcf for Zone 1 – Shell Placement Area and 100 pcf for Zone 2 – General Placement Area." If the static stability analysis is using 100 and 105 pounds per cubic foot as moist unit weights when those values are actually dry unit weights, then the static stability analysis is underestimating the gravitational stress on the filtered tailings facility. For that reason alone, the calculation of the factor of safety would be an overestimate.

Nothing in the discussion of the static stability analysis states the assumed height of the water table within the filtered tailings facility. In this respect, in such a dry environment, a water table (top of the region with saturated pores) within the filtered tailings facility would result probably not from naturally occurring groundwater, but from the water entrained within the filtered tailings, as well as from precipitation and surface runoff onto the filtered tailings facility. There is no discussion of the water table height that would result in the factor of safety dropping below FS = 1.5 nor the circumstances under which such a water table height could develop. In summary, although the static stability analysis indicates an acceptable factor of safety, the analysis should be regarded as entirely unreliable.

Adequacy of Water Management Infrastructure

The purpose of the diversion channels (contact water ditches) is to prevent rewetting of the filtered tailings by surface runoff (see Fig. 9). The design of the channels to accommodate a

24-hour storm with a return period of 10 years during mine operation means that, in any given year, the probability of overtopping of the channels will be 10%. On that basis, the probability that overtopping of the channels will occur at least once during the five years of mine operation is 41%, so that overtopping of the channels will essentially be an expected event. The available documents include no discussion of the consequences of overtopping of the diversion channels, including possible impacts on the stability of the filtered tailings facility or the possibility of liquefaction of the lightly-compacted tailings.

The design of the channels to accommodate a 24-hour storm with a return period of 100 years after mine closure means that, in any given year of the indefinite time period following mine closure, the probability of overtopping of the channels will be 1%. On that basis, the probability that overtopping of the channels will occur at least once during, say, the next 60 years (two human generations), is 45%, so that overtopping of the channels will essentially be an expected event for the grandchildren of the current residents of Cañon City. As before, the available documents include no discussion of the consequences of overtopping of the diversion channels, including possible impacts on the stability of the filtered tailings facility or the possibility of liquefaction of the lightly-compacted tailings. In summary, the proposed water management infrastructure for the filtered tailings facility is entirely inadequate.

DISCUSSION

When evaluating a proposed mining project, it is important to distinguish between shortcomings that can be potentially fixed and shortcomings that are fundamental flaws. Shortcomings that can be fixed require particular attention by the regulatory authorities, while fundamental flaws indicate that a mining project needs to be rethought from the very beginning with the possibility that a particular mining project might not even be possible at a particular location at a particular time. Such fundamentally flawed applications should be rejected by regulatory authorities without further consideration, or until a fundamentally different mining application is submitted.

This report has documented numerous shortcomings that are actually potentially fixable. For example, the diversion channels could be redesigned so that they could accommodate a much more extreme precipitation event, such as a 1000-year flood. As a second example, the seepage analysis that concluded that no liner would be necessary for the filtered tailings facility used incorrect input data. However, that shortcoming could be potentially repaired by requiring a liner or a double liner or a system of wells to capture and treat any water lost from the filtered tailings by seepage (as long as water treatment would not be required in perpetuity). As a third example, although there is still no plan for a water treatment plant for the water that is discharged from the contact water pond into the environment, such a plan could be required by the regulatory authorities prior to project approval (again, as long as water treatment would not be required in perpetuity). Without being overly cynical, it is not unusual for mining companies to leave out certain necessary aspects of a mining project (such as liners and diversion channels that are sufficiently large) in order to leave room for negotiation and compromise with regulatory authorities.

On other hand, the application for the Dawson gold mine includes three fundamental flaws that require rethinking of the project from the very beginning. The first fundamental flaw is the underestimation of the water consumption of the gold mine by an order of magnitude. It would be completely unacceptable for a regulatory authority to allow a mining project to go forward that was going to consume ten times as much water as it claimed that it was going to consume.

It is tempting to argue that any deficiencies in water for the mining operation could be made up simply by using more of the groundwater that flows into the underground mine. The current plan is that this water will be pumped into the contact water pond from which it will either evaporate or be discharged into the environment. According to Environmental Alternatives (2021a), "A MODFLOW ground water model was used to investigate changes to the water balance as a result of the mine development and dewatering and indicates dewatering rates ranging from approximately 80 to 55 gpm … On average, dewatering rates will be approximately 55 gpm based on the modelling … For the purpose of sedimentation pond [contact water pond] sizing, the pond should be designed around a discharge rate of 55 gpm." Additional water from mine dewatering of 55 gallons per minute would still not make up the anticipated water deficiency, but would be a start in the right direction. However, the source of the conclusion that average dewatering rates would be 55 gallons per minute is not clear. In fact, this information is not found in the section Appendix L: MODFLOW Modeling in Environmental Alternatives (2021b), nor is evidence for an average dewatering rate of 55 gallons per minute presented in any other available document.

The purpose of the assertion that average mine dewatering will be 55 gallons per minute is to argue that the contact water pond would be large enough to accommodate the water coming out of the underground mine. Other sections of the available documents argue that the mine dewatering could potentially be much less. For example, Environmental Alternatives (2021a) states, "These estimates [of mine dewatering of 55 gpm] are conservative in that they assumed the immediate dewatering of the mine form the bottom of the mine and assumes that the Precambrian material responds to pumping as a porous media and not a fractured rock aquifer. If the fractures in the Precambrian material are not connected, dewatering rates will be much lower once the fractures drain." The Technical Report states, "Groundwater inflow through the rock mass is not expected to be significant. Fracture porosity may carry some water into the underground workings near the surface. In the absence of detailed groundwater studies, groundwater infiltration is anticipated to be less than 100 gpm" (Golder Associates, 2017).

In summary, at the present time, there is certainly no assurance that mine dewatering could supply the probably necessary 100 gallons of water per minute. This is what is meant by a fundamental flaw that requires rethinking from the ground up. If there is no adequate source of water, then there is no way to construct a gold mine at the proposed location.

The second fundamental flaw is the assumption that water could be endlessly recycled through the mining operation with no chemical water treatment and no adverse effects. These adverse effects arising from a build-up of the dissolved solids content of the process water could include precipitation of salts onto all contact surfaces, clogging of pipes, clogging of the filter presses, and most importantly, the potential inability of the process water to function for the extraction of the gold concentrate. Finally, there is the problem of what to do with all of the saline process water when the mine is closed and the recycling of water ceases. The introduction of chemical water treatment into the mining circuit is not a minor matter and requires rethinking from the ground up.

The third fundamental flaw is the failure to acknowledge that the structural zone of the filtered tailings storage facility would constitute a dam and should conform to dam safety standards. This is not simply a matter of, say, the mining company agreeing to add a layer of rockfill as armor on the outer embankment of the structural zone. Thus far, there has not even been any consideration of state, national or international guidelines for dam safety. On that basis, at the present time, there is no way to know whether it is even possible to construct a safe tailings storage facility at this particular location. As with the other fundamental flaws, the means for safe permanent tailings management needs to be rethought from the ground up.

CONCLUSIONS

The chief conclusions of this report can be summarized as follows:

1) The available documents from Zephyr Minerals Ltd include numerous contradictions both internally and between documents. In particular, different input data are used for different types of analyses.
2) The predicted water consumption of 9.8 gallons per minute is 18.4% and 6.6% of the average for the gold mining industry, based on ore production and gold production, respectively, even after adjusting industry averages for the reduction in water consumption resulting from filtered tailings technology. A more reasonable water consumption would be 100 gallons per minute, which would need to be supplied from groundwater.
3) The predicted regional drawdown from dewatering the underground mine did not take into account the additional groundwater that would be pumped from a supply well. The dewatering calculation also did not consider the long-terms impacts of dewatering or the time required to restore the equilibrium of the groundwater system.
4) There is no plan for the treatment of mine water before it is released into the environment.
5) There is no mention of the possibility of water treatment for the water that is recycled through the mining operation and no analysis of the increase in the dissolved solids content of the process water that could occur due to recycling without treatment. In fact, saturation of the process water could result in precipitation of salts on all contact surfaces and in the tailings filter presses, which would render the filter presses non-functional. In addition, there is no discussion as to how the process water could still function to extract the gold concentrate with a high dissolved solids content.
6) The application never uses the word “dam” and does not recognize that the structural zone of the filtered tailings facility would constitute a dam that should conform to dam safety standards.
7) The structural zone/dam would be constructed using the upstream method in which the dam is built on top of the lightly-compacted tailings that it is confining. In the event of the liquefaction of the tailings, the dam will collapse into the underlying tailings. For that reason, the method of upstream construction is illegal in Brazil, Chile, Ecuador and Peru.
8) There is no consideration of the susceptibility to liquefaction of the lightly-compacted tailings confined by the structural zone or the circumstances under which liquefaction could occur.
9) The documents from Zephyr Minerals Ltd include no consideration of the consequences of failure of the filtered tailings facility. According to a statistical model of past tailings dam failures, following failure of the tailings dam at the Dawson mine, under the most-likely scenario (loss of 35% of the stored tailings after 5 years of operation), the tailings will travel 11,905 feet during the initial runout. Under the worst-case scenario (loss of 100% of the stored tailings after 5 years of operation), the tailings will travel 37,098 feet (over 7 miles) to Grape Creek and then to the Arkansas River and through the center of Cañon City during the

initial runout. Subsequent normal fluvial processes will transport the tailings indefinitely down the Arkansas River.

10) Based on Colorado, as well as most national and international dam safety standards, and the potential for loss of human life and habitat destruction following dam failure, the filtered tailings facility should be designed to withstand at least 90% of the Probable Maximum Precipitation (PMP).
11) Although the static stability analysis of the filtered tailings facility indicated an acceptable factor of safety, all geotechnical input parameters were assumed without justification. The tailings densities were based on measurements on tailings samples from a different ore deposit (Windy Gulch), an assumed ability to compact the tailings to 95% of the maximum density within the structural zone, and an apparent confusion between dry and moist unit weights. There was no mention of the assumed height of the water table or any discussion of the water table height that would result in dam instability or the circumstances under which such a water table height would occur.
12) The diversion channels for the filtered tailings facility would be designed to accommodate a 24-hour storm with a return period of 10 years during mine operation. On that basis, the probability of rewetting the tailings by runoff would be 10% in any given year of mine operation and 41% over the five years of mine operation. Following mine closure, the diversion channels would be reconstructed to accommodate a 24-hour storm with a return period of 100 years, so that the probability of rewetting the tailings by runoff would be 1% in any given year of the indefinite period of mine closure. There is no analysis of the consequences of rewetting either in terms of dam stability or increasing the susceptibility of the tailings to liquefaction.

RECOMMENDATIONS

The recommendation of this report is that the application for the Dawson gold mine should be rejected by the regulatory authorities without any further consideration.

ABOUT THE AUTHOR

Dr. Steven H. Emerman has a B.S. in Mathematics from The Ohio State University, M.A. in Geophysics from Princeton University, and Ph.D. in Geophysics from Cornell University. Dr. Emerman has 31 years of experience teaching hydrology and geophysics, including teaching as a Fulbright Professor in Ecuador and Nepal, and has 70 peer-reviewed publications in these areas. Dr. Emerman is the owner of Malach Consulting, which specializes in evaluating the environmental impacts of mining for mining companies, as well as governmental and non-governmental organizations. Dr. Emerman has evaluated proposed and existing mining projects in North America, South America, Europe, Africa, Asia and Oceania, and has testified on mining issues before the U.S. House of Representatives Subcommittee on Indigenous Peoples of the United States and the United Nations Permanent Forum on Indigenous Issues. Dr. Emerman is the Chair of the Body of Knowledge Subcommittee of the U.S. Society on Dams and one of the authors of Safety First: Guidelines for Responsible Mine Tailings Management.

Steven H. Emerman

REFERENCES

ANCOLD (Australian National Committee on Large Dams), 2012. Guidelines on tailings dams—Planning, design, construction, operation and closure, 84 p. Available online at: https://www.resolutionmineeis.us/sites/default/files/references/ancold-2012.pdf

Assembleia Legislativa de Minas Gerais [Legislative Assembly of Minas Gerais], 2019. Legislação Mineira (Lei 23291, de 25/02/2019) [Mining Legislation (Law 23291 of February 25, 2019)]. Available online at: https://www.almg.gov.br/consulte/legislacao/completa/completa.html?tipo=LEI&num=23291&ano=2019

BLM (Bureau of Land Management), 2021. Layer—BLM Colorado Areas of Critical Environmental Concern (ID: 0). Available online at: https://gis.blm.gov/coarcgis/rest/services/lands/BLM_CO_AreasCriticalEnvironmentalConcern/FeatureServer/0

Canadian Dam Association, 2013. Dam safety guidelines 2007 (2013 edition), 88 p.

Canadian Dam Association, 2019. Application of dam safety guidelines to mining dams (2019 edition), 61 p.

Cañon City, Colorado, 2021. Recreation. Available online at: https://www.canoncity.org/368/Recreation

Code of Colorado Regulations, 2019. Hard Rock Metal Mining: Department of Natural Resources, Division of Reclamation, Mining and Safety, 2 CCR 407-1, 127 p. Available online at: https://www.sos.state.co.us/CCR/GenerateRulePdf.do?ruleVersionId=8178&fileName=2%20CCR%20407-1

Code of Colorado Regulations, 2020. Office of the State Engineer Rules and Regulations for Dam Safety and Dam Construction: Department of Natural Resources, Division of Water Resources, 2 CCR 402-1, 48 p. Available online at: https://www.sos.state.co.us/CCR/GenerateRulePdf.do?ruleVersionId=8426&fileName=2%20CCR%20402-1

ColoradoView, 2021. Colorado GIS Data. Available online at: http://www.coloradoview.org/colorado-gis/

Crystal, C., C. Hore, and I. Ezama. Filter-pressed dry stacking—Design considerations based on practical experience: Tailings and Mine Waste 2018, 11 p. Available online at: https://www.srkexploration.com/en/publication/na-filter-pressed-dry-stacking-design-considerations-based-practical-experience

DoITPoMS [Dissemination of IT for the Promotion of Materials Science], 2021. Liquefaction. Available online at: https://www.doitpoms.ac.uk/tlplib/granular_materials/liquefaction.php

Environmental Alternatives, 2021a. Zephyr Gold USA Ltd's Designated Mining Regular (112d) Operation Reclamation Permit Application for Dawson Gold Mine—Fremont County, CO—Application and Exhibits: Submitted June 30, 2021, 129 p. Available online at: https://dnrweblink.state.co.us/drms/0/edoc/1336840/2021-07-02_PERMIT%20FILE%20-%20M2021046.pdf?searchid=9dcfe1bc-1453-4c0e-8b5c-ad6eac5eedc5

Environmental Alternatives, 2021b. Zephyr Gold USA Ltd's Designated Mining Regular (112d) Operation Reclamation Permit Application for Dawson Gold Mine—Fremont County, CO—Appendices: Submitted June 30, 2021, 426 p. Available online at: https://dnrweblink.state.co.us/drms/0/edoc/1336841/2021-07-02_PERMIT%20FILE%20-%20M2021046%20(2).pdf?searchid=9dcfe1bc-1453-4c0e-8b5c-ad6eac5eedc5

Espinosa-Gomez, R., S. Gomez-Hernandez, and P.D. Munro, 2018. Tailing filtration practices in Mexican gold and silver mines: 14th AusIMM Mill Operators' Conference 2018, Brisbane, Queensland, Australia, August 29-31, 2018, 8 p.

Fell, R., P. MacGregor, D. Stapledon, G. Bell, and M. Foster, 2015. Geotechnical engineering of dams, 2nd ed.: CRC Press, 1348 p.

FEMA (Federal Emergency Management Agency), 2013. Selecting and accommodating inflow design floods for dams: FEMA P-94, August 2013, 47 p. Available online at: https://www.fema.gov/sites/default/files/2020-08/fema_dam-safety_inflow-designs_P-94.pdf

Gagnon, A. and P. Lind, 2017. Evaluating the transition to filtered tailings at Cerro Negro: COM2017—The Conference of Metallurgists hosting World Gold Nickel Cobalt Proceedings, Canadian Institute of Mining, Metallurgy and Petroleum, 11 p.

GeotechniCAL, 2021. Stress in the ground. Available online at: http://environment.uwe.ac.uk/geocal/SoilMech/stresses/stresses.htm

Golder Associates, 2017. National Instrument 43-101 Technical Report for the Dawson Property, Colorado, USA: Submitted to Zephyr Minerals Ltd., Effective Date March 21, 2017, 267 p. Available online at: https://www.miningdataonline.com/reports/Dawson_PEA_03212017.pdf

GRID-Arendal, 2021. Global Tailings Dam Portal Project. Available online at: https://www.grida.no/activities/461

Gunson, A.J., 2013. Quantifying, reducing and improving mine water use: Ph.D. thesis, University of British Columbia, Vancouver, BC, 285 p. Available online at: https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0071942

Holtz, R.D., W.D. Kovacs, and T.C. Sheahan, 2011. An introduction to geotechnical engineering, 2nd ed.: Pearson, 863 p.

ICMM (International Council on Mining & Metals), 2020a. New Global Industry Standard on Tailings Management aims to improve the safety of tailings facilities in the mining industry. Available online at: https://www.icmm.com/en-gb/news/2020/new-global-industry-standard-on-tailings-management

ICMM (International Council on Mining & Metals), 2021. Association Members. Available online at: https://www.icmm.com/en-gb/members/member-associations

ICMM-UNEP-PRI (International Council on Mining & Metals-United Nations Environment Programme-Principles for Responsible Investment), 2020. Global industry standard on tailings management—August 2020, 40 p, Available online at: https://globaltailingsreview.org/wp-content/uploads/2020/08/global-industry-standard-on-tailings-management.pdf

Jeyapalan, J.K., 1981. Flow failures of some mine tailings dams: Geotechnical Engineering, vol. 12, pp. 153-166.

Klohn Crippen Berger, 2017. Study of tailings management technologies: Report to Mining Association of Canada and Mine Environment Neutral Drainage (MEND) Program, MEND Report 2.50.1, 164 p. Available online at: http://mend-nedem.org/wp-content/uploads/2.50.1Tailings_Management_TechnologiesL.pdf

Larrauri, P.C. and Lall, U., 2018. Tailings dams failures—Updated statistical model for discharge volume and runout: Environments, v. 5. Available online at: doi:10.3390/environments5020028

Ministerio de Energía y Recursos Naturales No Renovables [Ministry of Energy and Non Renewable Natural Resources] (Ecuador), 2020a. Anexo II—Guía técnica para la presentación de proyectos de diseño de los depósitos de relaves [Appendix II—Technical guide for the presentation of tailings deposit design projects], 31 p. Available online at: https://www.mingaservice.com/web/index.php/documento/categoria/legislacion-minera

Ministerio de Energía y Recursos Naturales No Renovables [Ministry of Energy and Non Renewable Natural Resources] (Ecuador), 2020b. Instructivo para la aprobación de proyectos de diseño, construcción, operación y mantenimiento de depósitos de relaves para la mediana y gran minería [Instructions for the approval of projects for the design, construction, operation and maintenance of tailings deposits for medium- and large-scale mining], 27 p. Available online at: https://www.mingaservice.com/web/index.php/documento/categoria/legislacion-minera

Ministerio de Minería (Chile) [Ministry of Mining (Chile)], 2007. Decreto Supremo nº 248—Reglamento para la aprobación de proyectos de diseño, construcción, operación y cierre de los depósitos de relaves—publicado en el Diario Oficial el 11 de abril de 2007 [Regulation for the approval of projects of design, construction, operation and closure of tailings reservoirs—published in the Official Gazette of April 11, 2007], 24 p. Available online at: https://www.sernageomin.cl/wp-content/uploads/2018/01/DS248_Reglamento_DepositosRelave.pdf

Minnesota Department of Natural Resources, 2021. March 12, 2021 TMM [Twin Metals Minnesota] responses to DNR-RGU [Department of Natural Resources-Responsible Governmental Unit] comments, 172 p. Available online at: https://files.dnr.state.mn.us/input/environmentalreview/twinmetals/pd/tmm-responses-to-dnr-rgu-comments-march-2021.pdf

Moreno, J.J., S. Kendall, and A. Ortiz, 2018. Dewatering options for management of fine gold tailings in Western Australian goldfields: In Jewell, R.J. and A.B. Fourie (eds.), Paste 2018—Proceedings of the 21st International Seminar on Paste and Thickened Tailings, Australian Centre for Geomechanics, Perth Australia, pp. 413-424. Available online at: https://papers.acg.uwa.edu.au/p/1805_34_Moreno/

Morrill, J., P. Sampat, U. Lapointe, J. Kneen, D. Chambers, S.H. Emerman, A. Maest, and B. Milanez, 2020. Safety first—Guidelines for responsible mine tailings management: Earthworks and MiningWatch Canada, 37 p. Available online at: https://earthworks.org/publications/safety-first-guidelines-for-responsible-mine-tailings-management/#:~:text=The%20safest%20tailings%20facility%20is,demand%20for%20primary%20raw%20minerals.

Mudd, G., 2007a. Gold mining in Australia—Linking historical trends and environmental and resource sustainability: Environmental Science & Policy, vol. 10, pp. 629-644.

Mudd, G., 2007b. Global trends in gold mining—Towards quantifying environmental and resource sustainability: Resources Policy, vol. 32, pp. 42-56

Mudd, G., 2007c. Resource consumption intensity and the sustainability of gold mining: 2nd International Conference on Sustainability Engineering & Science, Auckland, New Zealand, 20-23 February 2007. Available online at:

https://www.thesustainabilitysociety.org.nz/conference/2007/papers/MUDD-Gold-Mining-v-Sustainability.pdf
Mudd, G.M., 2010. The environmental sustainability of mining in Australia—Key mega-trends and looming constraints: Resources Policy, vol. 35, pp. 98-115.
Mudd, G.M., S.A. Northey, and T. Werner, 2017. Final report—Water use and risks in mining: RMIT University, December 2017, 33 p. Available online at: http://water.columbia.edu/files/2018/01/14.2017.Mudd_.Report.Water-Use-and-Risks-in-Mining.pdf
Norgate, T. and N. Haque, 2012. Using life cycle assessment to evaluate some environmental impacts of gold production: Journal of Clean Production, vols. 29-30, pp. 53-63.
Northey, S.A and Haque, N., 2013. Life cycle based water footprint of selected metal production—Assessing production processes of copper, gold and nickel: CSIRO, Australia, 43 p.
Petley, D., 2019. The speed of the Brumadinho tailings dam landslide: AGU100 Blogosphere—The Landslide Blog, February 4, 2019. Available online at: https://blogs.agu.org/landslideblog/2019/02/04/brumadinho-tailings-dam-landslide/
Sistema Nacional de Información Ambiental (Perú) [National System of Environmental Information (Peru)], 2014. Decreto Supremo N° 040-2014-EM .- Reglamento de protección y gestión ambiental para las actividades de explotación, beneficio, labor general, transporte y almacenamiento minero [Supreme Decree No. 040-2014-EM .- Regulation of protection and environmental management for the activities of exploitation, beneficiation, general labor, transport and mineral storage], 30 p. Available online at: https://sinia.minam.gob.pe/normas/reglamento-proteccion-gestion-ambiental-las-actividades-explotacion
Spiller, E. and R. Dunne, 2017. Reducing water usage in gold treatment—What is possible: COM2017—The Conference of Metallurgists hosting World Gold Nickel Cobalt Proceedings, Canadian Institute of Mining, Metallurgy and Petroleum, 10 p.
Tost, M., B. Bayer, M. Hitch, S. Lutter, P. Moser, and S. Feiel, 2018. Metal mining's environmental pressures—A review and updated estimates on CO2 emissions, water use, and land requirements: Sustainability, vol. 10, 14 p. Available online at: https://www.mdpi.com/2071-1050/10/8/2881/htm
Twin Metals Minnesota, 2021. Dry Stack Tailings Storage. Available online at: https://www.twin-metals.com/learning-center/dry-stack-tailings-storage/
Ulrich, B.F. and J.G. Coffin, 2017. Characterization of unsaturated tailings & its effects on liquefaction: Tailings and Mine Waste 2017, 10 p. Available online at: http://knightpiesold.com/es/noticias/publicaciones/characterization-of-unsaturated-tailings-its-effects-on-liquefaction/
USACE (U.S. Army Corps of Engineers), 1991. Inflow design floods for dams and reservoirs: Engineer Regulation ER 1110-8-2(FR), 10 p. Available online at: http://www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/ER_1110-8-2_FR.pdf
USACE (U.S. Army Corps of Engineers), 2014. Safety of dams – Policy and procedures: Engineer Regulation ER 1110-2-1156, 528 p. Available online at: http://www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/ER_1110-2-1156.pdf

USACE-HEC (U.S. Army Corps of Engineers – Hydrologic Engineering Center), 2003. Application of paleohydrology to Corps flood frequency analysis: RD-47, 34 p. Available online at: http://www.hec.usace.army.mil/publications/ResearchDocuments/RD-47.pdf

USACE (U.S. Army Corps of Engineers), 2021. National Inventory of Dams. Available online at: https://nid.sec.usace.army.mil/ords/f?p=105:1

USGS (U.S. Geological Survey), 2021. National Hydrography Dataset. Available online at: https://www.usgs.gov/core-science-systems/national-geospatial-program/national-hydrography